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ORIGINAL ARTICLES.

The Structure of the Pacific Basin.

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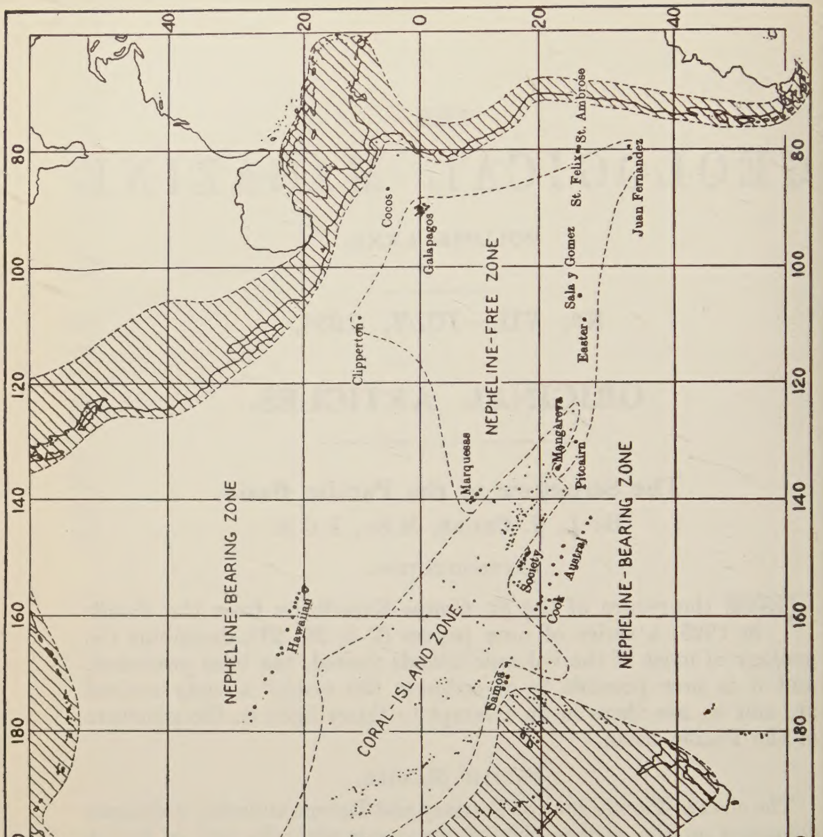
Introduction.

SINCE the return of the *St. George* Expedition from the Pacific in 1925, a series of nine papers (2–8, 26, 27), describing the geology of most of the volcanic islands visited, has been published, and it is now possible to co-ordinate the results already arrived at, and to use them in an attempt to throw light on the structure of the Pacific basin.

Pacific Margin.

The circum-Pacific zone of Tertiary and Recent andesitic volcanoes coincides on the eastern side of the ocean with the belt of folded mountains of western America. On the northern and western sides, however, it extends far out beyond the existing continental margins, and embraces many groups and festoons of islands. Most authorities are agreed that this part of the andesitic zone represents an area of continental land, that was gradually folded, fractured, and submerged in Mesozoic and Tertiary times. Many of the andesites contain an appreciable proportion of virtual free silica, so that they approach dacites in composition, and in many islands they are associated with rocks of continental types. The existing fauna and flora of these islands shows marked affinities with that of the neighbouring continents.

A comparison of the map showing the distribution of rock-types (Fig. 1) with that showing ocean depths (Fig. 2) proves that the floor of the submerged parts of the andesitic zone is exceedingly irregular. Most of the islands are arranged in arcuate or linear groups, situated on ridges, which are generally separated by enormous


NEPHELINE-BEARING ZONE
NEPHELINE-FREE ZONE
CORAL-ISLAND ZONE
NEPHELINE-BEARING ZONE
Cocos
Galapagos
Clipperton
Marquesas
Hawaiian
Caroline
Samoa
Society
Cook
Austral
Pitcairn
Mangareva
Easter
Sala y Gomez
St. Felix
St. Ambrose
Juan Fernandez
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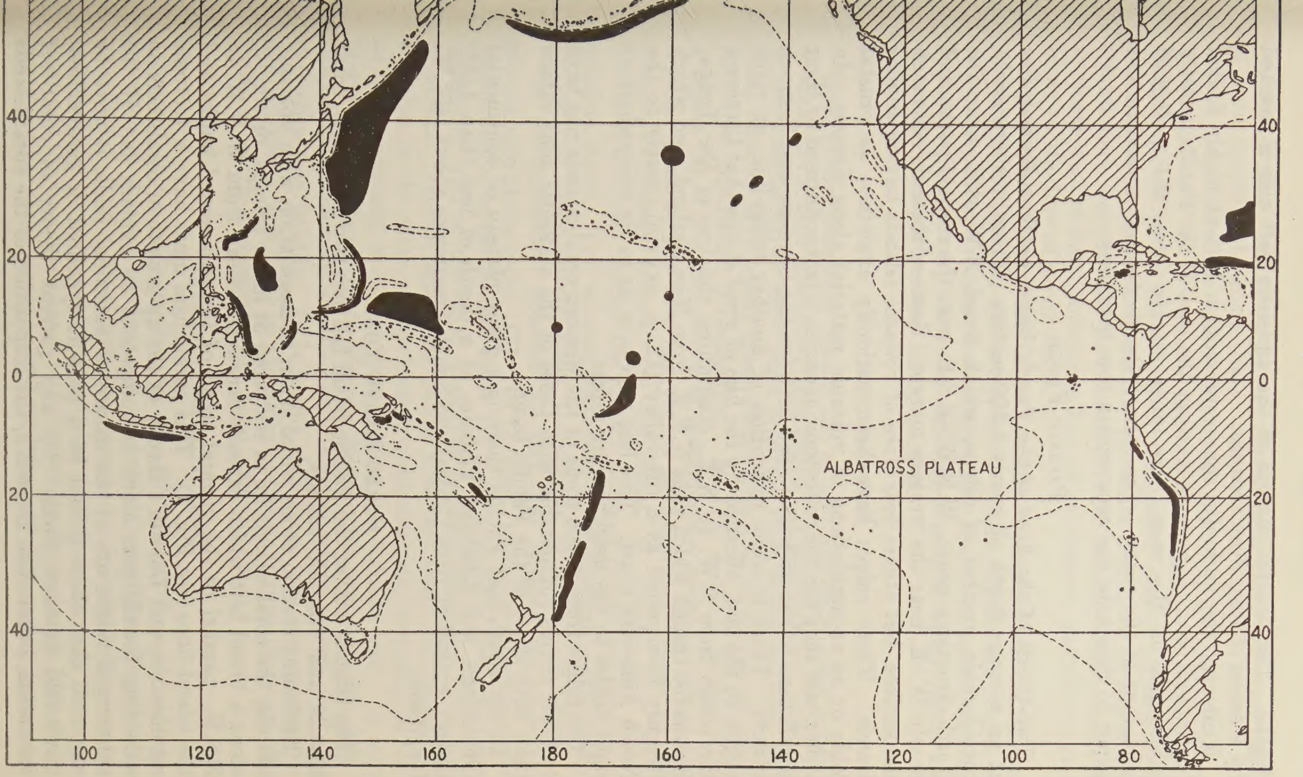


FIG. 2.—Pacific Ocean, depths, based on the latest edition of the Admiralty charts. Broken line : 4,000 metre depth-contour. Black : areas where depth exceeds 6,000 metres.

depths. The oceanic margin of the andesitic belt also is marked by a series of long deep troughs.

Evidently the andesitic zone represents a belt of highly folded continental land, above sea-level on the east of the Pacific, mostly submerged on the west. Its inner margin forms the geological boundary of the ocean. The term " Pacific basin " is used in this paper to designate the area within this boundary.

PACIFIC FLOOR.

Two-thirds of the floor of the Pacific basin, as thus defined, lies at an average depth of nearly 5,500 metres. From it there rise a considerable number of ridges, which trend N.W.–S.E. near the North American coast, W.N.W.–E.S.E. over the central parts, and nearly W.–E. near the western margin. Some of these do not reach the surface, but others bear lines of volcanic islands having similar trends. These ridges have been variously explained as crustal folds or as accumulations of volcanic material along fissures. In either case they are due to tectonic agencies, a fact confirmed by their parallelism to the andesitic zone between the Caroline and Samoan islands. There is some indication of another trend-line, at right angles to the last, afforded by the line of great deeps that traverses the ocean from S.W. to N.E., continuing the line of the Tonga-Kermadec trough which runs N.N.E. from New Zealand, and which Gregory interpreted as a rift-valley (12, p. cxxxiii), nearly to the North American coast. This line curves so as to lie everywhere at right angles to the neighbouring ridges.

The ridges from which some of the western coral-islands rise have variable trends comparable with those of the andesitic zone rather than with those of the Pacific basin.

In the south-east Pacific there is a great plateau of continental dimensions, the Albatross Plateau, at a depth of less than 4,000 metres, extending from Central and South America to about 145° W. longitude.

CORAL ISLAND ZONE.

The islands within the Pacific basin fall into two categories, coral islands and volcanic islands.

Excluding certain atolls which occur in association with volcanic islands, the coral-islands lie in scattered or linear groups, or singly, along a broad belt which extends across the ocean from W.N.W. to E.S.E., parallel to the general trend of the submerged banks and the island-lines (see Fig. 1). This parallelism must have a tectonic significance, and Darwin's theory of the up-growth of coral-reefs on subsiding foundations alone is competent to explain it. If the submerged ridges are of the nature of anticlinal folds, it is to be expected that there should be a parallel synclinal or geosynclinal down-fold between them. By any current theory of coral-reef formation, other than Darwin's, the disposition of the coral-islands is inexplicable, and must be attributed to accidental coincidence, a most improbable assumption.

The coral-islands situated south of the Equator and between 150° and 170° W. longitude are arranged along lines trending N.N.E.–S.S.W., the second trend mentioned above. These lines are continued southward, outside the main boundary of the coral-island zone, between the Samoan and Cook Islands. They seem to indicate a subsidiary transverse line of subsidence, parallel to and close to the line of great deeps.

About nine of the islands in the zone have been uplifted to altitudes of from 30 to 250 feet above sea-level. These islands are scattered irregularly along the zone, but nearly all lie near to its south-western margin, which may perhaps be suffering a general uplift, following an earlier subsidence (see later, p. 296).

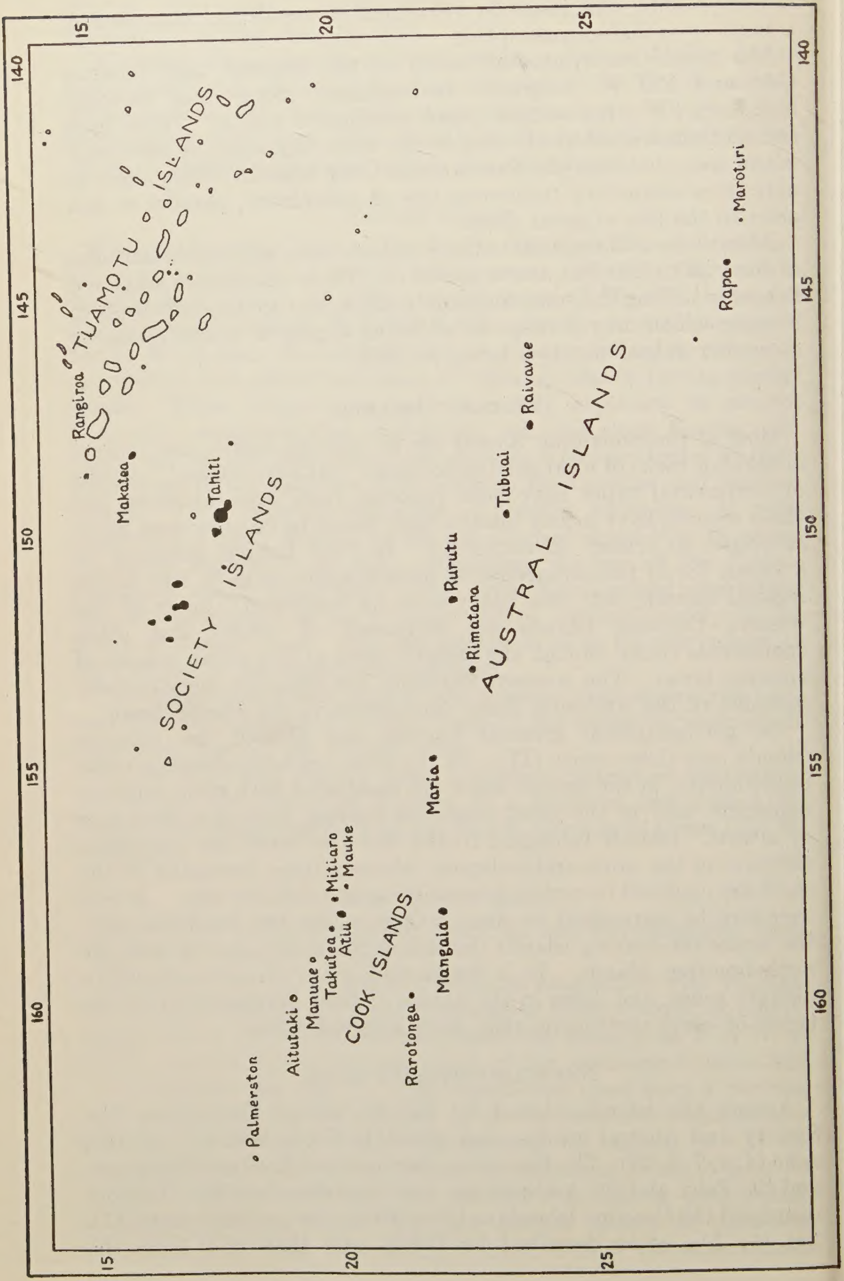
VOLCANIC ISLANDS.

Most of the remaining islands are of volcanic origin, and consist of alkaline rocks of what used to be called " Atlantic facies ". Rocks of continental types have been reported from some of them, but these records have nearly always been found to be erroneous when subjected to critical investigation. In 1927 I gave publicity to a report (3) of the occurrence of metamorphic rocks in two of the Austral Islands, but this has yet to be confirmed. Some of the western Caroline Islands are composed of schists and other continental rocks, though the eastern parts of this group consist of alkaline lavas. The western Carolines are therefore provisionally included in the Andesitic Zone, the eastern in the Pacific basin.

On petrographical grounds Lacroix has divided the volcanic islands into three series (17). In the first, nepheline-bearing rocks predominate, in the second these are associated with rocks without nepheline, and in the third nepheline-bearing rocks are very rare or absent. Islands belonging to the first two series are associated together in the same archipelagoes, whereas those belonging to the third are confined to certain groups lying in a definite area. It will therefore be convenient to discuss them under two headings only, the nepheline-bearing islands (including the mixed series), and the nepheline-free islands. It is found that these two series occur in distinct zones, and differ in the nature of their foundations and the types of earth-movement that have affected them.

NEPHELINE-BEARING ZONE.

Among the islands visited by the *St. George* Expedition, the Society and Austral groups, and probably Cocos Island lie in this zone (3, 4, 7, 8, 27). The Hawaiian, Samoan, and Cook archipelagoes, and St. Felix and St. Ambrose are also nepheline-bearing. Lacroix dismissed the Caroline Islands as lying within the andesitic zone (17), but the five rocks described by Hobbs and Hunt (14) from the


140
145
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155
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TUAMOTU ISLANDS
Rangiroa
Makatea
Tahiti
SOCIETY ISLANDS
Rurutu
Rimatara
Tubuai
Raivavae
AUSTRAL ISLANDS
Rapa
Marotiri
Maria
Mangaia
Mitiaro
Mauke
Atiu
Takutea
Manuae
Aitutaki
COOK ISLANDS
Rarotonga
Palmerston

eastern members of this group were all alkaline basalts, one of them with nepheline, and their analyses show that three others contain virtual nepheline.

Most of the islands in this zone show a linear grouping, and rise from submerged ridges that have the dominant W.N.W.–E.S.E. trend. It seems likely that these ridges are anticlines produced by lateral pressure along a N.N.E.–S.S.W. direction, for gravity observations in the Hawaiian Islands show large positive anomalies (16, p. 197), suggesting that stresses have raised this group too high for isostatic equilibrium. Fissures of the nature of strike-faults, and having the same trend as the anticlines, have opened up, and through them lavas have been extruded and volcanoes erected. In places other fissures, of the nature of dip-faults, and trending N.N.E., have been produced.

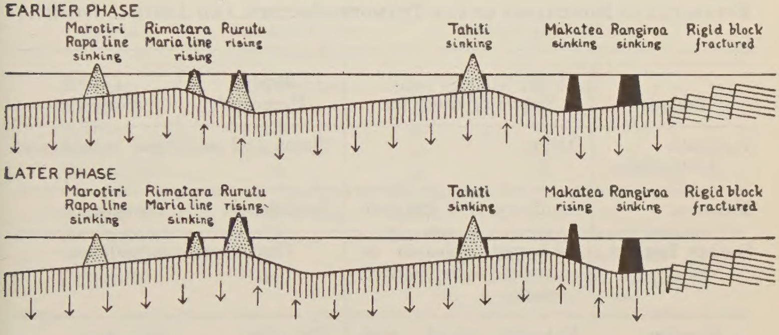

FIG. 4.—Diagrammatic sections, not to scale, showing the movements of the Tuamotu, Society, and Austral Islands. Volcanic Islands dotted; coral-reefs black.

The ridges represented on the map (Fig. 2) as underlying the Society and Austral Islands are largely hypothetical, as few soundings have been made here. Recently Howel Williams has questioned the existence of these ridges, especially that supposed to underlie the Society Islands (29, pp. 6–7), basing his views chiefly on soundings made by the *Carnegie*. The route of this ship, however, lay chiefly near the northern margin of the presumed ridge, and variable depths up to nearly 4,000 metres were found. When she turned south-westward, between the Leeward and Windward members of the group, the bottom rose to about 3,000 metres from the surface. To the north-east the depths soon attain 4,300 metres and to the south-west over 4,000 metres. The available facts suggest the presence of a ridge, similar to that known to underlie the Hawaiian Islands.

The presence of moving anticlines is suggested by the geological histories of the individual islands, as shown by elevated coral-reefs and plateaux, and by embayed river-valleys, barrier-reefs, and atolls, the latter being taken as evidence of subsidence. The essential information concerning the movements of these islands is tabulated in Table 1. If this table be compared with the map (Fig. 3) and the diagrammatic sections (Fig. 4), it will be seen that the two anticlines are slowly migrating towards the N.N.E., with a wave-like motion.

The Cook Islands have not shared in this movement, although they probably stand on the same fissures as the Austral Islands. As Marshall has shown (22, p. 7), the whole group has been tilted along a fulcrum-line running N.E.–S.W., the islands to the east of this line having risen, and those to the west of it having subsided. The evidence for this movement is given in Table 2. The tilting is probably connected with the situation of these islands close to the

TABLE 1.

EVIDENCES OF MOVEMENTS OF THE TUAMOTU, SOCIETY, AND AUSTRAL ISLANDS.

Islands.		*Nature of Evidence.*	*Earlier Movement.*	*Later Movement.*
Tuamotu Archipelago.		Atolls.	Great and prolonged subsidence.	
Makatea.		Atoll, uplifted 230 feet.	Subsidence.	Elevation.
Society Islands.		Embayed volcanic islands, with barrier-reefs.	Considerable subsidence.	
Austral Islands.	Rurutu.	Volcanic island, with plateau at 800 feet, and uplifted reef at 300 feet above sea-level.[1]	Elevation.	Elevation.
	Maria	Limestone island, with barrier-reef.	Elevation.	Subsidence.
	Rimatara.	Volcanic island, with older reef uplifted 30 feet and new barrier-reef.	Elevation.	Subsidence.
	Tubuai and Raivavae.	Not yet investigated, but with barrier-reefs.	?	Subsidence.
	Rapa and Marotiri.	Deeply embayed volcanic islands, too far south for barrier-reefs.	Considerable subsidence.	

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[1] If W. M. Davis's view be accepted, that the uplifted reef on Rurutu is a barrier-reef (11, p. 402), a period of subsidence must have intervened between the two periods of elevation (see also 4, 21, 15).

eastern margin of the southern branch of the coral-island zone, where subsidence has been extreme. Marshall's view that the Austral Islands shared in the tilting (22, p. 9) would require reefs uplifted some 250 feet on Maria, and nearly 300 feet on Rimatara. It is contradicted by the slight elevation of the old reefs and the development of new barrier-reefs around these islands (3). The Cook Islands may perhaps be separated from the Austral Islands by a fault trending N.E.

The western end of the Society island-group, which consists of atolls, may also possibly have suffered a downward tilt towards the southern branch of the coral-island zone.

TABLE 2.

EVIDENCES OF THE TILTING OF THE COOK ISLANDS (CHIEFLY AFTER MARSHALL).

Islands.	*Approximate distance from fulcrum-line.*	*Nature of Evidence.*
Mangaia . .	130 miles.	Reef uplifted 200 feet.
Mauke . .	85 ,,	,, ,, 100 ,,
Mitiaro . .	60 ,,	,, ,, 92 ,,[1]
Atiu . .	45 ,,	,, ,, 70 ,,
Rarotonga .	13 ,,	,, ,, 20 ,,
	Position of fulcrum-line.	
Manuae . .	20 miles.	Atoll.
Aitutaki . .	75 ,,	Small volcanic island with barrier-reef 8 miles in diameter.
Palmerston .	280 ,,	Atoll, in the southern branch of the coral-island zone.

NEPHELINE-FREE ZONE.

In this zone the *St. George* Expedition visited the Marquesas, Galapagos, and Easter Islands (5, 6, 7, 26). Mangareva, Pitcairn, Sala y Gomez, and the Juan Fernandez Islands also lie within it, and Clipperton Island may be provisionally assigned to it (28). The Marquesas and Galapagos are the only archipelagoes in the zone, the other islands being widely separated and lying along a sinuous line in about 25° S. latitude.

These islands show no linear grouping and there is no evidence that any of them rise from anticlinal or other ridges. The islands of the Marquesan group have a scattered arrangement, and appear to stand on the points of intersection of two sets of fissures, which trend respectively N. 7° W. and N. 83° E., and thus make angles of about 45° with the trend-lines of the Tuamotu, Society, and Austral lines. The pressure from the S.S.W. that produced the folds underlying the latter islands may well have been responsible for the fissuring of the crust under the Marquesan Islands, provided that this portion of the crust is too resistant to be thrown into folds. Similarly the Galapagos Islands appear to stand on two sets of fissures trending respectively nearly N.E. and N.W. These could have been produced in a rigid platform by pressure along an E.–W. line, such as that which has folded the neighbouring South American Andes. These two archipelagoes show evidence of faulting along lines parallel to the fissures, and some of the southern islands in the zone also appear to have been faulted.

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[1] Marshall does not mention the amount of uplift of Mitiaro. He states that it is composed entirely of limestone, so presumably its altitude (quoted from the Admiralty chart) is a correct measure of its uplift.

Thus the islands within this zone show differences from those in the nepheline-bearing zone, not only in the facies of their rocks, but also in the nature of their foundations and the type of earth-movement with which they have been associated. The conclusion seems unavoidable that the part of the sea-floor from which they rise differs in essential characters from the parts underlying the nepheline-bearing islands.

A comparison of Figures 1 and 2 shows that all these islands stand on and generally near the margins of the Albatross Plateau. It seems probable that this plateau forms a rigid block, that has resisted the pressure that has been brought to bear upon it from all sides, except that around its margins it has been fissured and faulted.

That part of the plateau that lies between the Marquesas and Mangareva, however, seems to have become involved in the sagging of the coral-island belt. There are a number of atolls in this region, all of which show a scattered arrangement, similar to that of the islands of the Marquesan and Galapagos archipelagoes, and which therefore probably stand on submerged nepheline-free volcanoes. Their grouping is quite different from the linear arrangement of the atolls lying immediately to the west, which are probably in the nepheline-bearing zone.

Part of the eastern end of the Albatross Plateau has to some extent shared in the subsidence that produced the Peruvian deep.

The lavas of the nepheline-free zone closely resemble those of the nepheline-bearing zone, except that they contain enough silica to saturate the alkalies. Many indeed contain a fair proportion of virtual free silica. Perhaps a similar magma fed them all, but in the nepheline-free zone it had to ascend through a certain thickness of highly siliceous rocks. If so it might be expected that some of the latter would be absorbed, and would produce exactly those differences in the lavas that are actually found.

For this reason it is suggested that the Albatross Plateau is a submerged block of sial.

Conclusions.

Very diverse views have been expressed by different authors on the past history of the Pacific Ocean. Extreme advocates of the doctrine of Isostasy hold that its boundaries and depths have always been very much the same as they are now. Supporters of Wegener's theory of Continental Drift have had little to say about the Pacific, but it would be a remnant of Panthalassa, considerably reduced in size, owing to the advance of America from the east having been more rapid than the retreat of Asia and Australia towards the west. The islands, whether andesitic, nepheline-bearing, nepheline-free, or coral, would presumably stand on fragments of sial that have become detached from the margin of the retreating continents. It would be difficult to explain the distribution of the different rock-types on this theory. Further, if the mountain-chains of western America owe their origin to the rucking of the advancing front of the continent, the submerged mountains that underlie the andesitic zone on the north and west must have had a similar origin, so that, instead of a westerly drift, a centripetal thrust towards the Pacific from all directions would seem to be necessary, as Daly suggests (10, p. 278). Meinesz has shown (24, p. 665) that the isostatic anomalies over the great deeps and their neighbouring islands indicate that the western part of the andesitic zone is subject to strong tangential pressure, and that Wegener's assumption of a sucking effect behind westwardly-moving islands is not in harmony with the results.

Other authorities postulate the former existence of land-bridges across the Pacific. Recently the late Professor J. W. Gregory summarized all the available information bearing on this subject (12), including that based on the stratigraphy of the oceanic margins, and on the distribution of past and present organisms. He showed that there is a great deal of evidence in favour of direct land-connections across the Pacific in past geological ages. Such connections are required chiefly across the north Pacific, connecting North America with north-eastern Asia, and across the south Pacific, connecting South America with Australia and south-eastern Asia. The work of the *St. George* Expedition was almost entirely confined to the south Pacific, and so the southern land-bridge alone will be considered.

The average width of the southern Pacific from Australia to South America is nearly 9,000 miles. It has been shown, however, that the andesitic zone represents a foundered continental area, and the minimum distance from its margin to the South American coast is only some 6,700 miles. If the Albatross Plateau is a submerged block of Sial, it is quite conceivable that it formerly stood above sea-level, forming a great tract of continental land. The distance from its western end to the nearest point on the andesitic zone is only about 2,000 miles.

In a recent account of the geology of Easter Island (7), much evidence was brought forward to show that this island has not formed part of a tract of continental land since its occupation by man, as certain ethnologists and popular writers have suggested. There is no evidence, however, that the island does not rise from a submerged continental block, indeed the presence among its lavas of rhyolites, and of andesites containing virtual free silica and resembling the andesites of western South America, suggests that it may do so.

The distance to be bridged has thus been enormously reduced. The intervening area is so mobile that there is little difficulty in believing that it may have risen above sea-level and subsided again several times during geological history.

It may be argued that the foundering of an area of the size of the Albatross Plateau to a depth of some 4,000 metres would be a contravention of the principle of isostasy, and is therefore impossible. Yet few would deny the continental origin of the western andesitic zone, though its average depth is still greater. Parts of it have sunk to a depth considerably exceeding twice that of the Albatross Plateau, indeed the greatest known oceanic depth, 10,793 metres, or nearly six and three-quarter miles, lies in the heart of the zone, with islands containing rocks of definitely continental types, such as granite, syenite, serpentine, and schists, on both sides of it.

The Albatross Plateau, together with that part of the andesitic zone lying between Australia, New Zealand, Samoa, and the Carolines, may well have formed part of a trans-Pacific extension of the hypothetical continent of Gondwana-land, for, as Professor Gregory pointed out, neither the marine fauna nor the terrestrial flora gives any evidence of the existence of a Carboniferous Pacific Ocean (12, p. lxxxv). Published reconstructions show Gondwanaland, not as a southern continent as it is so often described, but as an equatorial continent, extending from about 40° N. to 40° S. of the equator. It may well have completely encircled the globe. Its emergence may perhaps have been due to a temporary lag in the lithosphere's adjustment to the decreasing speed of the earth's rotation, the equatorial bulge becoming too prominent relatively to the form that the hydrosphere had come to assume, in the manner suggested by Professor A. E. H. Love (18).

Gravity determinations made over the Albatross Plateau may soon be available. Observations of the speed of surface earthquake-waves over this region are desirable, and the Marquesas Islands are ideally situated for a seismological station to undertake this work. Here the velocity of waves from Chile and Peru could be compared with that of those from California, Japan, New Zealand, and the other circum-Pacific earthquake centres.

Except that two or three islands close to the Central American coast have not yet been described, the publication of this paper marks the conclusion of my work on the Pacific Islands, arising out of the *St. George* Expedition of 1924–5. During the progress of the work I have received financial assistance from the Department of Scientific and Industrial Research, the British Museum (Natural

History), the Government Grants Committee of the Royal Society, and the Bernice P. Bishop Museum of Honolulu. I should like to record my gratitude to these institutions, as well as to those friends in all parts of the world who by encouragement, criticism, and information have helped me to bring the work to a conclusion. Professor W. B. R. King has kindly read the manuscript of this paper and made valuable suggestions.

So far as material is available, complete collections of all the rocks that have been described will be presented to the British Museum (Natural History) and the Bernice P. Bishop Museum, and smaller collections to the Muséum National d'Histoire Naturelle of Paris and the Smithsonian Institution of Washington.

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Age-Problems of the Moine Series of Scotland.

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Introduction.

The *Chapters on the Geology of Scotland*, by B. N. Peach and John Horne, reveals very clearly the complete divergence in the views of these two masters concerning certain fundamental problems of the Moine Series. Peach (1, pp. 199–200) [1] regards the Moine Series as the equivalent of the Torridonian and its metamorphism as entirely post-Cambrian. Horne (1, pp. 200–1), on the other hand, believes the Moine Series to consist mainly of sedimentary schists of pre-Torridonian age which formed part of the land-barrier separating the Cambrian sea in the North-West Highlands from that in which the fossiliferous Highland Border Rocks (Cambro-Ordovician) were laid down.

The early history of the controversy concerning the age of the Moine Series has been admirably summarized by Horne in the Geological Survey Memoir on the North-West Highlands (2, ch. ii). An account of more recent developments is also available (3, pp. 112–117). It may fairly be said that there are four groups of opinions on this subject.

(1) *The Moine Series is of Lower Palaeozoic age, and received its metamorphic character during the Caledonian orogeny.*

Among Scandinavian geologists, Gustav Frödin (4, pp. 224, 235) holds that the Moine metamorphism is of post-Cambrian date and that considerable portions of the Highland Schists are of Lower Palaeozoic age. It may be recalled that Charles Lapworth (5) suggested that Central Sutherland was in all probability an intimate compound of Archaean, Ordovician, and intrusive rocks, metamorphosed into schists in post-Silurian time. Von Bubnoff (6), in his *Geologie von Europa*, whilst apparently favouring Frödin's interpretation (6, vol. ii, pt. i, pp. 97–8), appears to conclude (6, p. 131) that the Moine metamorphism is probably older than the last Caledonian movements.

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[1] Numbers and page references refer to the Bibliography given at the end of this paper.

(2) *The Moine Series is the equivalent of the Torridonian, and its metamorphism is post-Cambrian in date.*

The view that the Moines are Torridonian metamorphosed in post-Cambrian time is associated with the name of Peach; there are adherents among Scottish geologists but their faith has not yet been committed clearly to print. C. T. Clough, while presenting the best evidence for this view, regarded it as not proven (7, p. 46).

(3) *The Moine Series is post-Lewisian but pre-Torridonian in age, and its metamorphism is pre-Torridonian.*

This view may be regarded as that generally held by Scottish geologists. John Horne (1, pp. 200–1) has advanced certain evidence in its favour, little of which appears to me to be of much cogency. J. W. Gregory (8, p. 447) showed the occurrence of pebbles indistinguishable from Moine granulites in the basal Torridonian of Little Loch Broom; this identification was accepted by Horne and approved by Teall (1, p. 76). I have pointed out that granulites of Moine type are said to occur among the Lewisian rocks of Lewis, and among the Loch Maree sedimentary series associated with the mainland Lewisian, and these may have furnished the pebbles in question (3, p. 117).

The post-Lewisian age of the Moine Series depends upon the existence of Lewisian Inliers in the Series. This is based on the field-work of E. M. Anderson, C. T. Clough, B. N. Peach, and others, and on the petrographical work of Sir John Flett (references in 3, pp. 115–16). In brief, the evidence is as follows: the occurrence of local basal conglomerates in the Moine Series; the overlap of the Moine Series on to Lewisian rocks; the asymmetrical arrangement with regard to their periphery of the paragneisses within the Lewisian Inliers; and the dissimilar metamorphic histories and characters of the two groups.

(4) *The Moine Series, like all Highland Schists, is of Lewisian age and its metamorphism is Lewisian.*

This opinion was held by George Barrow, who denied the existence of Lewisian Inliers. His interpretation may be pieced together from his discussions on various papers dealing with the structure and metamorphism of the Highlands read before the Geological Society of London in recent years (especially 9, pp. 110–11).

Some New Evidence Available.

The mapping of the great Moine area, considerably over 1,000 sq. miles in extent, of Northern Ross, South and Central Sutherland, by the Geological Survey has now been completed. The rocks have been described by me (3, 10, 11). During this work certain new lines of evidence bearing on the age-problems of the Moine Series have been developed. Further, I had the opportunity of examining and comparing the sliced rocks from the Northern Highlands in the Geological Survey Collection. Finally, during the last few years I have made visits, brief it is true, to certain localities, such as Glenelg, Western Ross, and Western Sutherland, that are important in this discussion.

The consideration of this new evidence seems necessary now that Peach's and Horne's views are clearly stated. It is particularly desirable, also, in view of the tendency of Scandinavian geologists to regard more and more of their portions of the Caledonian mountain-chain as consisting of Lower Palaeozoic rocks metamorphosed in Palaeozoic times. The Scandinavian view will be bound to have repercussions in Scotland.

During the discussion of the main arguments used in support of the various views listed already, I shall summarize this new evidence and show how the old conclusions are affected by it.

AGE OF THE MOINE METAMORPHISM.

There are two great connected problems of the Moine Series: the age of the general metamorphism, and the age of the Moine rocks. These questions may be considered separately.

It has been the custom till quite recently to regard the metamorphism of the Moine Series as a simultaneous event throughout the extent of this great rock-formation. I believe that this view is incorrect. I propose, therefore, to call the uniform metamorphism characterizing the Northern Highlands away from the Moine Thrust and the Great Glen the *general Moine metamorphism*. It is characterized by the development of garnet in pelitic rocks over a very great area. Two views are before us with regard to the age of this metamorphism :—

(*a*) it is earlier than the post-Cambrian movements.
(*b*) it is caused by these movements.

The Alkaline Igneous Rocks of the Northern Highlands.

An argument used by both Frödin (4, p. 224) and Peach (1, pp. 199–200) in favour of the post-Cambrian date of the Moine metamorphism is that the post-Cambrian alkaline igneous rocks of the Assynt district (2, chs. xxix and xxx) belong to the same intrusion-period as the granites of Inchbae and Carn Chuinneag in Ross-shire. The Inchbae and Carn Chuinneag intrusion has been shown by C. B. Crampton, C. T. Clough, and J. S. Flett (12, p. 73; 13, p. 337) to be clearly earlier than the general metamorphism of the Moine Series. The recent recognition (11, pp. 174–9) of the alkaline nature of the Ben Loyal syenite in North Sutherland radically affects the conclusion of Frödin and Peach.

The beautiful mountain-group of Ben Loyal, south of Tongue in North Sutherland, is formed of an intrusion, 12 sq. miles in size, piercing siliceous and semipelitic rocks of the Moine Series. The clear intrusive relations, the contact-metamorphism of Moine rocks adjacent to the intrusion, and the completely non-metamorphic character of the igneous rocks show that the intrusion is later than the general Moine metamorphism. Examination of a small but representative suite of specimens from the igneous mass reveals that the chief type is pulaskite, whilst nordmarkite is less abundant. The Ben Loyal mass therefore consists of alkali-syenites intruded into the Moine granulites after these had attained their general metamorphic characters. The Ben Loyal syenites are identical with rocks forming part of the post-Cambrian syenite mass of Loch Ailsh in the Assynt district of Sutherland described by J. Phemister (3, pp. 22–111). This identity even extends to details of microscopic structure and of optical characters of the constituent minerals. For instance, the nature, distribution, and arrangement of the perthitic intergrowths in the feldspars in the two masses agree in every particular; aegirine-augite and hornblende form identical associations in the two series, whilst the accessory components are the same and show the same properties in the two rocks. The analyses of a pulaskite from Ben Loyal and of one from the Loch Ailsh intrusion are remarkably similar, a similarity all the more striking when the small choice of material for analysis from the Ben Loyal mass is taken into account.

Analyses of the rocks of the Inchbae augen-gneiss massif show a close similarity to those of the alkaline suite of Assynt. For instance, the aegirine-felsite of Assynt (2, p. 449) closely resembles in chemical composition the two analysed acid rocks of Inchbae, the granite-gneiss, and the aegirine-riebeckite-gneiss (12, p. 92). On the chemical side there is no objection to the identity of the two suites, though structurally and texturally they have little in common. Since the similarity of the alkali-syenites of Assynt and Ben Loyal is so extremely well marked, any correlation of Inchbae and Assynt rocks leads to the simultaneous correlation of Inchbae and Ben Loyal. The result is, therefore, to identify two igneous suites one of which is definitely earlier than the general Moine metamorphism and the other entirely later. Whilst the identity of the Assynt and Ben Loyal rocks is so complete that they must be considered to belong to the same igneous episode, the strongly contrasting facies of the Inchbae rocks shows they must belong to an earlier period of intrusion altogether. Since the Assynt rocks are affected by the post-Cambrian thrusting, and since the Ben Loyal rocks are later than the general Moine metamorphism, it follows on this view that the post-Cambrian movements are later than the general Moine metamorphism and that they affected rocks that had already been subjected to this metamorphism. In any case the argument of Frödin and of Peach can no longer be considered of value.

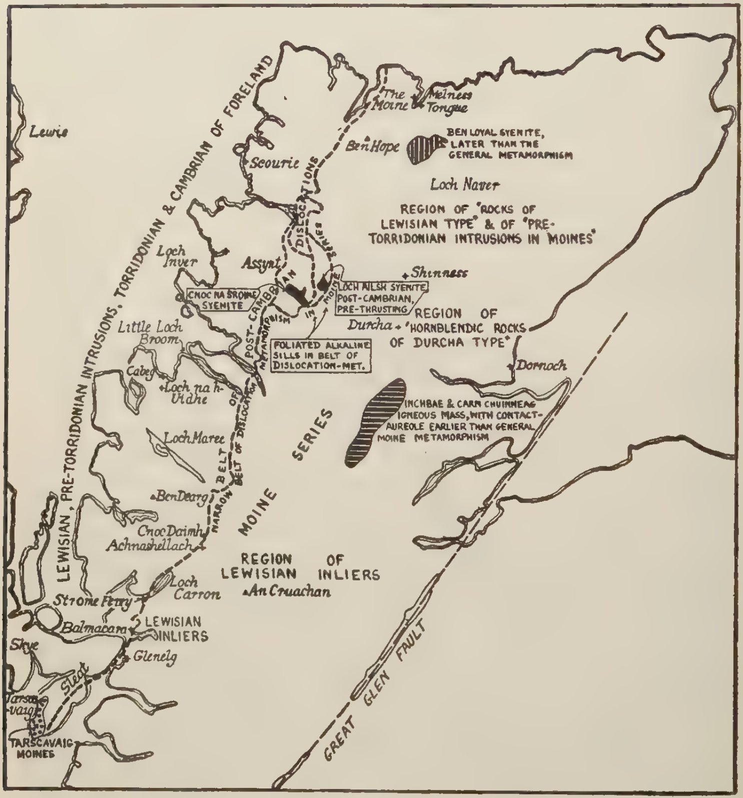
Lewis
LEWISIAN, PRE-TORRIDONIAN INTRUSIONS, TORRIDONIAN & CAMBRIAN OF FORELAND
The Moine
Melness
Tongue
Ben Hope
BEN LOYAL SYENITE, LATER THAN THE GENERAL METAMORPHISM
Scourie
Loch Naver
REGION OF 'ROCKS OF LEWISIAN TYPE' & OF 'PRE-TORRIDONIAN INTRUSIONS IN MOINES'
DISLOCATIONS
SERIES
Loch Inver
Assynt
Shinness
CNOC NA SROINE SYENITE
POST-CAMBRIAN METAMORPHISM IN MOINE
LOCH AILSH SYENITE POST-CAMBRIAN, PRE-THRUSTING
REGION OF 'HORNBLENDIC ROCKS OF DURCHA TYPE'
Durcha
Little Loch Broom
FOLIATED ALKALINE SILLS IN BELT OF DISLOCATION-MET.
Dornoch
Cabeg
Loch na h-Uidhe
OF BELT OF DISLOCATION
INCHBAE & CARN CHUINNEAG IGNEOUS MASS, WITH CONTACT-AUREOLE EARLIER THAN GENERAL MOINE METAMORPHISM
Loch Maree
SERIES
NARROW BELT
Ben Dearg
MOINE
Cnoc Daimh
Achnashellach
REGION OF LEWISIAN INLIERS
Loch Carron
An Cruachan
Strome Ferry
Balmacara
LEWISIAN INLIERS
Skye
Glenelg
Sleat
Tarscavaig
TARSCAVAIG MOINES
GREAT GLEN FAULT

FIG. 1.—Some Factors concerned in the Age-problems of the Moine Series.

The Belt of Low-grade Metamorphism adjacent to the Moine Thrust.

A belt of low-grade metamorphism in the Moine Series adjacent to the outcrop of the Moine Thrust has been encountered over a considerable distance. Peach and Horne say (1, p. 177), " The grade of metamorphism along the Moine line of disruption for a distance of 100 miles is comparatively low but increases eastwards from that plane." In this belt in the Assynt district, alkaline sills, presumably belonging to the post-Cambrian suite of that region, are foliated in accord with the surrounding country-rocks.

Two conclusions have been drawn from these undisputed facts. The *first conclusion* is that the low-grade belt represents Moine rocks metamorphosed under a lower load than farther east, but that there is only one episode of metamorphism. In Peach's words (14, p. 27), " The phenomena of the belt of thrusting are but a marginal phase, produced under less load, of the folding and consequent deformation that prevailed over the whole of the area of metamorphic rocks to the east of that belt." Teall, with his usual caution, gave two alternatives in connection with this belt, for he stated (2, pp. 599–600), " The question has arisen as to whether they [i.e. the low-grade rocks near the Moine Thrust] represent crystalline schists more or less broken down or sedimentary rocks which are on the way, so to speak, to become Moine-schist." The second of Teall's alternatives has been that favoured by most who have dealt with this belt of low-grade rocks.

The *second conclusion*, based upon the existence of presumably post-Cambrian sills with a foliation agreeing with that of the low-grade belt, states that therefore the Moine metamorphism is of post-Cambrian age.

In my opinion, the unity of the Moine metamorphism is open to question. Evidence from Central Sutherland (11, pp. 43–50) shows that the belt of low-grade metamorphism represents " crystalline schists more or less broken down ". In that region, I have called the low-grade zone " the belt of dislocation-metamorphism ". In it the structural lines found in the central area of Moine rocks have been pulled into alignment with the trend of the Moine Thrust, and petrographical examination shows that the onset of the dislocation-metamorphism can be traced in gradually increasing steps from Moine rocks of the general metamorphism to thorough mylonite-schiefer, mylonite-gneisses, and mylonites. The dislocation-metamorphism is undoubtedly superposed upon the general Moine metamorphism.

Biotite is often a conspicuous component of the rocks of the belt of dislocation-metamorphism. Its presence has been held by some with whom I have discussed this subject to militate against the formation by dislocation-metamorphism of the rocks containing it. I have recently shown (15), however, that the stability of biotite in repeated metamorphism in Unst, Shetland Islands, depends fundamentally upon the bulk chemical composition of the rocks concerned. In pelitic rocks, biotite is not stable under the conditions of dislocation-metamorphism, but in quartz-feldspar-biotite-granulites and similar rocks it is unaltered, except mechanically. The Moine granulites are of exactly the same type of rocks that, in Unst, retain their biotite under dislocation conditions. This point has a bearing also on the production of biotite in such rocks as the Tarscavaig-Moines, dealt with on a later page.

I am therefore of the opinion that the general metamorphism and the dislocation-metamorphism are two separate events in the history of the Moine Series. Examination of thin sections of Moine rocks of the north coastal district of Sutherland leads to a result that in some ways is to be regretted. I find that the rocks of The Moine, the type and name area of the Moine Series, are not like the great majority of rocks that make this, the most widespread formation of Scotland, for they have suffered the dislocation as well as the general Moine metamorphism. It is not until the localities of Melness and Tongue, to the east of The Moine, are reached that there are found Moine rocks showing only the general metamorphism.

The dislocation-metamorphism arises from the post-Cambrian movements that are of late Caledonian age. Can the general Moine metamorphism be considered to result from an earlier phase of the same orogeny ? Frödin, von Bubnoff, and others would answer this question in the affirmative. F. E. Suess (16, pp. 79–80) holds that the Moine Thrust has no immediate relations to the Caledonian structure proper, but is independent of and younger than this mountain-building. He suggests that in the Caledonian orogeny the Moines, with their post-tectonic crystallization, acted as the " creative block " which, moving south-eastwards, overwhelmed the Dalradian rocks whose " tectonic structure and metamorphic facies have been impressed on them by the load and movement of the superimposed mountain mass " (16, p. 78). The two earth-movements of Colonsay described by W. B. Wright (17) may be advanced as a Scottish example of the time-spacing of metamorphic events connected with Caledonian movements. But these, though separated in time, are of similar type. So far as I know, the Moine area has as yet supplied no evidence on this question. If it cannot be shown that the general metamorphism and the dislocation-metamorphism are not both of Caledonian age, it certainly cannot be shown that they are both of this age.

Conclusions, so far reached, as to the Age of the Metamorphism.

So far in this discussion I have endeavoured to show, on the evidence of the alkaline rocks of the Northern Highlands and of the polymetamorphic character of the Moine rocks near the Moine Thrust, that the post-Cambrian movements of the great dislocation areas in the North-West Highlands found the Moine rocks with their general Moine metamorphism already impressed upon them. These two metamorphisms may be a late and an earlier phase of the Caledonian orogeny, whilst just as likely they may be two distinct episodes separated by the half of geological time. Certain evidence connected with the rocks of Lewisian Type occurring in the Moine Series of Central Sutherland that has a bearing on the age of the general Moine metamorphism is given on a later page.

AGE OF THE MOINE SERIES.

The question of the age of the Moines considered as a sedimentary series may now be taken up. The several views on this are :—

(1) The Moine Series is of Lower Palaeozoic age.
(2) It is Torridonian in age.
(3) It is pre-Torridonian, post-Lewisian in age.
(4) It is Lewisian in age.

(1) *The Moine Series is of Palaeozoic Age.*

In this view the age of the Moine metamorphism is concerned. This has already been discussed, and many of the points raised in later pages have a bearing on the issue.

(2) *The Moine Series is Torridonian.*

The view that the Moine Series and the Torridon Sandstone are the same was advanced mainly by Peach (14, p. 30 ; 18, p. 262 ; and compare C. T. Clough, 7, p. 8, p. 46). Peach pointed out that the local basal conglomerate of the Moine Series bears a resemblance to the basal conglomerate found in the infolded Torridonian rocks of the Diabaig group that are involved in the crushed gneiss below the Moine Thrust in the region between Strome Ferry and Balmacara and, further, that the phyllites of admitted Torridonian age on Cnoc Daimh, in the Achnashellach Forest, are indistinguishable from the phyllites associated with the quartzo-feldspathic granulites above the supposed position of the Moine Thrust in that region. Peach concluded that " the difference between the rocks of sedimentary origin on either side of the Moine Thrust-plane in the Loch Carron region is thus shown to be one of degree of alteration and not of kind " (14, p. 30). Just as Peach indicated that metamorphosed Torridonian comes to resemble Moines, so does Clough point out that little-altered Moines resemble Torridonian. The Tarscavaig-Moines of Sleat, Skye, appear to be transitional in degree of metamorphism between Torridonian and Moines (7, p. 45). Clough stated that " the unaltered representatives of a large part of the Tarscavaig-Moine Series must have had considerable resemblance to the Diabaig rocks of the Torridonian formation " (7, p. 46). He further indicated, however, that there were no representatives in the Moine Series of the epidotic grits and conglomerates which are found at the base of the Diabaig division, and the coarse granulite of the Moines was more siliceous than the common grit of the Diabaig division. After suggesting other criticisms, Clough felt " that the evidence at present available does not warrant the conclusion that the Moine rocks represent Torridonian rocks. They may do so, but this remains to be proved " (7, p. 46).

A few words to introduce the Tarscavaig-Moines may not be out of place. They occur in the Sleat district of Skye (see Fig. 1) to the north-west of the Moine Thrust. They lie upon the Tarscavaig

Thrust, a plane of dislocation on a lower level than the Moine Thrust. They are associated with small exposures of rocks referred to the Lewisian. Clough states that they clearly belong to the " same great formation as the Moine rocks on the south-east side of the Moine thrust " and " they are yet in a decidedly less altered condition, and help to fill up the gap in degree of metamorphism between the most altered of those rocks which can with confidence be claimed as Torridonian and the more common types of Moine rocks " (7, p. 45). Clough describes the rock-types making up the Tarscavaig-Moines as phyllites and schistose grits. Abundant white mica is present, but biotite is scarce, occurring as occasional spots or rare porphyroblasts in a few rocks. Microcline is found to make up a good proportion of the pebbles in the grits.

I had the opportunity of examining the Geological Survey collection of sliced rocks from the Tarscavaig-Moines, and from Torridonian and Moine occurring near the post-Cambrian dislocations. The Tarscavaig-Moines are, in my opinion, cataclastically sheared rocks, and are exactly like the rocks derived from Torridonian in the neighbourhood of the great thrusts. There appears to be no reason for considering them as anything else than Torridonian affected by the post-Cambrian dislocations. This identification raises an important topic, that that I have elsewhere called *metamorphic convergence* (15).

If an act of metamorphism affects rocks of the same bulk chemical composition it will produce similar results whatever the previous metamorphic histories of the rocks may have been. The metamorphic convergence will arise in the area affected during the episode in question. This is excellently illustrated in Unst where identical rocks are produced by the dislocation-metamorphism from such diverse assemblages as staurolite-kyanite-garnet-gneiss, chloritoid-chlorite-schist, chloritoid-kyanite-schist, and hitherto non-metamorphosed pelitic sediments.

I suggest that in the North-West Highlands the post-Cambrian dislocation-metamorphism has produced very similar rocks where it has acted upon rocks of somewhat similar composition. The Torridonian Sandstone and the dominant quartz-feldspar-muscovite-biotite-granulite of the Moines are alike in composition, and in the neighbourhood of the great dislocations they both give rise to rocks of the dislocation-facies that are thoroughly similar [see also J. W. Gregory (8)]. The recognition of two distinct phases in the metamorphism of the Moine Series—the dislocation-metamorphism and the general metamorphism—is a fundamental factor in this interpretation, for it disposes of those arguments supposed to show a metamorphism transitional from unaltered Torridonian to true Moine rocks. The latest metamorphic event, the post-Cambrian thrusting, has naturally produced similar results in all rocks of similar composition, but this similarity is confined to the neighbourhood of the dislocations.

I may conclude this section of this discussion, therefore, by stating that arguments based on similarities in Moine and Torridonian rocks where these are affected by the post-Cambrian movements have no value in connection with the equivalence of the Moine and Torridonian formations.

(3) *The Moine Series is pre-Torridonian and post-Lewisian in age.*

This view may be discussed from three aspects, (i) Gregory's Moine pebbles in Torridonian conglomerates, (ii) the existence of Lewisian Inliers, and (iii) the new evidence from Central Sutherland.

(i) The find of pebbles indistinguishable from Moine rocks in the Torridonian of Little Loch Broom by J. W. Gregory (8) may indicate that the Moine Series is of pre-Torridonian age. Certain other possible sources of these pebbles have already been mentioned and, until the possibilities of a Lewisian source are completely excluded, it is perhaps best to suspend judgment on this point. There may here be recalled the arguments listed by Horne (1, pp. 200–1) in favour of a pre-Torridonian age for the Moine Series: There is no Torridonian in the displaced masses west of the Moine Thrust in North Sutherland, suggesting that the Torridonian sandstone was not an essential factor in the production of the Moines; there is no corresponding variation in lithological distribution as between Torridonian and Moine; there is no real basal conglomerate at the base of the Moine Series that can compare with the basal Torridonian conglomerate; the siliceous granulites of the Moine Series are more siliceous than the Torridonian grits.

(ii) The question of the Lewisian Inliers of Sutherland, Ross, and Inverness may now be examined. A full summary of their characters will be found in Peach and Horne's *Chapters* (1, pp. 155-171), and only a short account is needed here. From the petrographical account given by Sir John Flett (19) it is seen that the commonest rocks are hornblende-gneisses, associated with amphibolites and epidiorites. Other types are biotite-hornblende-gneiss, pyroxene-hornblende-gneiss, biotite-gneiss, and muscovite-biotite-gneiss. Eclogitic types are important for possible correlation, as are also the ultrabasic dykes—now modified peridotites and pyroxenites. The foregoing are regarded as of igneous origin, and the paragneisses are represented by calc-silicate-rocks and limestones, muscovite-biotite-schists occasionally with kyanite, and graphite-schists with rare andalusite.

This assemblage of orthogneisses and paragneisses undoubtedly closely resembles the Lewisian and associated pre-Torridonian intrusions of the foreland west of the post-Cambrian dislocations. Peach and Horne's summary of the Lewisian Inliers (1, pp. 170-1) is: "The evidence indicating the probable unconformity between the Moine Series and the inliers of Lewisian Gneiss may thus be summarized:—

"(1) The dominant members of the inliers of Lewisian Gneiss east of the Moine Thrust are gneisses of igneous origin (orthogneisses) resembling types in the Lewisian Gneiss areas west of the belt of post-Cambrian complication in the counties of Sutherland and Ross, while the characteristic members of the Moine Series are schists and gneisses of sedimentary origin.

"(2) The orthogneisses of the Lewisian inliers have produced, in some instances, contact metamorphism of the Lewisian paragneisses of sedimentary origin, but not of the adjoining Moine sediments.

"(3) At a few exceptional localities a conglomerate has been recorded at the base of the Moine rocks where they are in contact with the inliers of Lewisian Gneiss.

"(4) Along the line of junction between the Moine rocks and the Lewisian inliers different bands of Lewisian orthogneisses and paragneisses come into contact with the Moine schists, and different zones in the Moine Series abut against the Lewisian rocks."

As already mentioned, there is no doubt about the similarity, amounting almost to identity, between the rocks of the Lewisian inliers and the Lewisian of the unmoved foreland. In view, however, of the occurrences of andalusite on a "regional" scale in metamorphic areas I should not attach perhaps so much importance to the presence of andalusite in the An Cruachan graphite-schist as indicating a contact-metamorphism of Lewisian sediments that was not shared by the adjacent Moine sediments.

With regard to the existence and nature of the basal Moine conglomerate, it is unfortunate that this rock is practically unknown to the present generation of Highland geologists. I have examined the evidence only in the Glenelg region, where the relations are described by Clough (7, pp. 50-1). There I came to the conclusion that while there was a pebbly layer at the side of the Moines adjacent to what had been taken as Lewisan, still it could not be considered as an undoubted basal conglomerate. The great majority of the "pebbles" were quartz segregations of metamorphic origin, and the whole "pebbly" horizon was, in effect, of no more value than many other pebbly layers known throughout the mass of the Moine sediments (e.g. 3, pp. 114, 120, 121; 12, pp. 20-2, etc). Further, a glance at the Glenelg map, Sheet 71 of the Geological Survey map of Scotland on the scale of 1 inch to a mile, shows that some very remarkable relationships between Moine and "Lewisian" are there present; very narrow belts of one formation run in the other for great distances along the strike. It is difficult to consider that here an unconformity could be demonstrated.

In the case of the other localities of the basal Moine conglomerate, I have nothing to say as I have not visited them. It would be a great service to Highland Geology if some responsible commission were to visit and report on the outcrops of the Basal Moine Conglomerate.

(iii) *The New Evidence from Central Sutherland.*

Certain very important evidence is now available from Central Sutherland. Among the Moine Series in this district there occur large areas of rocks characterized by the presence of abundant hornblende. These rocks are like those making up the Lewisian Inliers of Ross-shire whilst many of them can be compared with rocks from the Lewisian of the foreland. I have shown that among these *Rocks of Lewisian Type* of Central Sutherland there occur hornblende-gneisses, hornblende-biotite-gneisses, hornblende-pyroxene-gneisses, pyroxene-gneisses, scapolite-gneisses, biotite-gneisses, biotite-granulites, and old pegmatites that can be matched with types in the Lewisian Inliers (11, p. 67). No calcareous rocks are known from Central Sutherland. Further, " in the same way, many of the rocks of Lewisian Type of Central Sutherland can be matched with material from the Lewisian Gneiss of the North-West Highlands. Hornblende-gneisses, hornblende-biotite-gneisses, hornblende-pyroxene-gneisses, biotite-gneisses, muscovite-biotite gneisses (both of Cabeg and Ben Dearg types [2, pp. 69-70]) are similar in the two groups. Further, rocks of the possibly sedimentary belt of Loch na h-Uidhe, Gruinard [2, pp. 187-9] resemble fairly closely sliced material from the Loch Naver area " of Central Sutherland (11, p. 68).

It has been mentioned above that the Lewisian Inliers of Ross-shire are intruded by a series of ultrabasic and basic rocks that can be closely compared with the pre-Torridonian intrusions in the Lewisian Gneiss of the foreland. Exactly similar rocks are found in the Rocks of Lewisian Type of Central Sutherland. Forty small masses consisting of serpentine, tremolite, chlorite, and talc, occur in the Rocks of Lewisian Type. Basic masses are not so abundant; they comprise amphibolite, hornblende-schist, and hornblende-rock. Further, the eclogitic suite is represented by rocks made up of pyroxene, hypersthene, hornblende, garnet, feldspar and quartz.

It may be concluded, therefore, that the Rocks of Lewisian Type of Central Sutherland, the Lewisian Inliers of Ross-shire, and the Lewisian Gneiss of the Foreland all contain identical orthogneisses, paragneisses, and ultrabasic and basic intrusives. In Central Sutherland, however, no evidence pointing to a discordance between the Rocks of Lewisian Type and the Moine Series has been detected. No basal Moine Conglomerate, no overlap or unconformity, and no metamorphic differences have been found. On the contrary, what have been taken as marginal interbandings have been observed and a common system of folding certainly affects both groups (11, p. 69).

The most important result from Central Sutherland may now be discussed. Basic and ultrabasic intrusions occur *in the Moine Series* that are identical with those found in the rocks of Lewisian Type, and therefore with those in the Lewisian Inliers and in the Lewisian of the foreland (11, ch. vi). Bosses of rocks composed of olivine, serpentine, tremolite, chlorite, and anthophyllite have been encountered in undoubted Moine rocks, epidiorites and hornblende-schists of types similar to those in the Rocks of Lewisian Types are abundant, whilst eclogitic amphibolites are also known from the Moine Series. Further, augen-granites of similar facies penetrate both Moines and Rocks of Lewisian Type. Finally, it is possible that in Leitir Mhuiseil, Ben Hope, two small masses that show a conversion of gabbro into hornblende-schist exactly similar to that described in the classic paper on the Scourie dyke by Teall (20) are surrounded by rocks of the Moine Series. It is unreasonable to suggest that the nature of the country-rock of these intrusions has been wrongly identified and that it is really Lewisian, though indistinguishable from Moines, or that the igneous masses are Lewisian Inliers without a shred of their country-rock attached to them.

From this new evidence the opinion is therefore advanced that the general metamorphism affecting rocks of the Moine Series and those of Lewisian Type in Central Sutherland was one and the same. There is a similarity, amounting in many cases to complete identity, between the orthogneisses, paragneisses, and ultrabasic and basic intrusions in Rocks of Lewisian Type, Lewisian Inliers, and unmoved Lewisian Gneiss of the foreland. Further, ultrabasic and basic intrusions identical with those occurring in these rocks of Lewisian facies are found in the Moine Series. In the Lewisian Gneiss of the unmoved foreland, these intrusives have been proved to be of pre-Torridonian age (2, ch. vii). The conclusion is warranted, therefore, that the Moine Series and its general metamorphism are of pre-Torridonian age.

(iv) *The Moine Series is Lewisian in age.*

As already mentioned, George Barrow maintained with his customary vigour that the entire Highlands were of Lewisian Gneiss age and denied the existence of Lewisian inliers in Moine rocks (e.g. discussion to 9, pp. 110-11). In connection with this interpretation I may again give a summary of certain results of the mapping of South and Central Sutherland (Sheets 102, 103, 108, and 109). These deal with what I have called Hornblendic Rocks of Durcha Type (3, pp. 144-7 ; 10, pp. 18-20)

The Hornblendic Rocks of Durcha Type were first encountered at Durcha in Strath Oykell (Sheet 102). They were afterwards found west of Dornoch (Sheet 103). These hornblendic rocks show usually an exceedingly fine striping and occur as bands of varying width, often about one-twelfth of an inch, in normal Moine granulites. There is obtainable a perfect transition from hornblendic rocks to normal siliceous granulites by innumerable intermediate striped and banded varieties. It is impossible in the field to draw any kind of rigid division between these hornblendic rocks on the one hand and siliceous Moine granulites on the other.

Hand-specimens of the rocks are striped with hornblendic, epidotic, and quartzo-feldspathic layers of marked regularity. Among the minerals making up the bands are hornblende, epidote, pyroxene, biotite, sphene, oligoclase, quartz, orthoclase, apatite, and iron oxide. In a granulitic base of quartz and feldspar occur bands formed of the other components. Some of the striping is produced by a line of scattered crystals of hornblende or of epidote or of pyroxene in the quartzo-feldspathic base. These rocks cannot be explained by any form of lit-par-lit intrusion, since lines of scattered mafic minerals occur in real siliceous granulite. A sedimentary origin for the series seems to meet the facts (3, pp. 144-7 ; 10, pp. 18-20).

The southern parts of Sutherland (Sheets 102 and 103) were mapped and described before Central Sutherland (Sheets 108 and 109) was dealt with. In the south the rocks of Durcha Type were found in such slender stripes in great areas of normal Moine rocks that the question of two different series such as Moine and Lewisian appeared to be ruled out. One hesitated to report Lewisian Inliers consisting of a single crystal of hornblende or pyroxene. When Central Sutherland was investigated, however, it appeared probable that rocks of Durcha Type entered very largely into the composition of what were finally described as Rocks of Lewisian Type of that area (11, pp. 67-9).

Comparison of the Central Sutherland rocks of Lewisian Type with those of true Durcha Type occurring farther south shows that, while the Durcha Type is in general finer in grain and more consistently granulitic in structure, yet the two groups are of similar facies. Again, certain of the hornblendic granulites of the Durcha group approach the granulitic gneisses from the Lewisian Gneiss (2, pp. 63-5, pl. xlv, fig. 2), whilst others, such as some from Shinness, can be well matched in the Cabeg gneiss of the same formation (11, p. 68). Further, much of the rock styled Lewisian Inliers of the Glenelg region adjacent to the basal Moine conglomerate to which reference has already been made appears to me to be very similar to Durcha rocks. The same similarity is seen by comparing Durcha rocks with those parts of the Lewisian Gneiss involved in the pre-Torridonian shear-belts of the Loch Inver district of West Sutherland.

From the foregoing it would appear reasonable, provided one dealt with the evidence from Sutherland only, to consider that rocks of Durcha Type, of Lewisian Type, and the Moine Series were one and indivisible. But the evidence for the inlier character of the rocks of Lewisian type in Ross-shire (Lewisian Inliers) has still to be reckoned with. Again the findings of an impartial commission on these inliers would be of value in this discussion. Whilst we may consider it possible that all signs of unconformity between Moine and Lewisian have been removed in Sutherland by tectonic agencies, still I maintain that I can produce the field-evidence that the Durcha type is an integral part of the Moine Series. I suspect that hornblende has been used in the past far too readily as an index for Lewisian. It must be admitted, I think, that rocks that would once have been called Lewisian on sight occur as part of the Moine Series. The full implications of this must wait till further work has been done in Ross-shire. Possibly George Barrow may have been right after all.

Conclusion.

In the foregoing pages an endeavour has been made to give a synopsis of the views, and of the evidence on which these are based, concerning certain age-problems of the Moine Series. Results from Central and South Sutherland suggest that this series and its metamorphism are of pre-Torridonian date, whilst a Lewisian age is not excluded. Most of these results are based upon comparative petrography, and this method of attack may be questioned. But it is the best weapon to our hand and, though we are at present inexpert in its use, still with time we shall prevail. It is obvious to the reader that there are dozens of problems connected with this subject that await investigation and solution. The writer hopes that this discussion will attract workers, especially those who are not afraid of making mistakes, into a field where they will find their efforts fully rewarded.

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The Corallian Rocks in the New Railway-Cutting at Westbury, Wilts.

By W. J. Arkell, M.A., B.Sc., D.Phil., F.G.S.

NEW loop-ways on the Great Western Railway to by-pass stations at Westbury and Frome have recently provided complete sections of Corallian Beds and Cornbrash.

The loop-way at Westbury was commenced late in 1930 and a cutting takes it through the ridge formed by the Corallian Beds. As an embankment was required across an adjoining stretch of low-lying Oxford Clay and the material from the cutting was insufficient, the sides were further quarried to provide the additional ballast. These operations were continued until after the summer of 1932.

The Westbury cutting has recently been described by Mr. P. M. Mathew.[1] Since it affords the only complete section of the Corallian formation in the district it is of great stratigraphical importance. An appreciation of this importance prompts me to put the present account on record, differing as it does fundamentally from the description of Mr. Mathew.

My description was made on 8th August, 1932, when the sides were sloped but not turfed; the most important part of the section, however, was as well exposed as could be desired in the large quarry adjoining the track. Work was still in progress on removing some of the Kimeridge Clay but had ceased in the main part of the cutting, so that I was able to study the succession all day undisturbed and record fossils bed by bed. The basal Kimeridge Clay with *Ostrea delta* W. Smith, and the Upper Calcareous Grit (Westbury Ironstone and subjacent sands) presented no features of special interest and have been well exposed for many years in the adjacent ironstone workings. The upper part of the Osmington Oolite Series, with its pisolitic marl, was also already well known from neighbouring exposures. Special attention was therefore devoted to the part of the section from the lower half of the Osmington Oolite Series downwards. The strata immediately above the Lower Calcareous Grit were studied in minute detail, with the object of detecting and defining any representative there might be of the Berkshire Oolite Series.

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[1] "Description of G.W.R. Cutting at Westbury, Wiltshire": *Proc. Bristol Nat. Soc.*, **4**, vii, pt. v, 1932, 382–7.

Mr. Mathew separates the Osmington Oolite Series from the subjacent strata, which he calls " Oxfordian ", by a low-angle fault, of which I detected no suggestion. Since that was the very part of the section to which I devoted the longest scrutiny, I cannot believe that were this fault really present I could have failed to detect or at least suspect it.

The description and classification of the strata in my note-book, with careful field-records of the fossils, are as under. It should be added that the cutting runs east–west, south of and nearly parallel with the old Frome line, and is crossed by a bridge carrying the Westbury Leigh–Fairwood–Rudge road, a mile and a quarter west of the centre of Westbury. The dip is about 12°–15° S.E. The measurements were taken on the north side of the line, east of the road bridge.

	Ft.	in.
KIMERIDGE CLAY.		
Poorly fossiliferous except for *Ostrea delta* W. Smith. Mr. Mathew saw	36	0
CORALLIAN BEDS.		
Upper Calcareous Grit.		
15. The Westbury Ironstone: crowded with the usual fossils: *O. delta*, *Ringsteadiae*, *Mactromya aceste* (d'Orb.), *Chlamys midas* (Damon), *Pleuromya*, etc..	10	0
14. Ferruginous and yellow sands	6	0
Osmington Oolite Series.		
13. Cream-coloured and white pisolite, as in old quarry ; passing down into typical false-bedded white oolite, as at Calne Workhouse, etc. Fossils usual, not recorded . . .	32	0
Berkshire Oolite Series.		
12. Dark iron-grey and greenish-grey clay	2	6
11. Clay with band of small ironstone concretions . . .		3
10. Brown and grey clay with some small white pellets and many *Exogyra nana* (Sow.).	1	6
9. Drab semi-indurated oolitic marl, like the Urchin Marls of Highworth: *Exogyra nana, Pleuromya* " *tellina* " (= " *decurtata* "), *Belemnites oxyrrhynchus* Lhuyd.	1	9
8. Brown and grey clay and sandy marl with thin seam of sand and many white pellets ; *Exogyra nana* and *Serpulae* . .	5–6	0
7. Pebble and Shell Bed. Loose and rubbly-weathering consolidated brown marl and shells: abundant *Gervillia aviculoides* Sow., *Trigonia hudlestoni* Lyc., *Chlamys fibrosa* (Sow.), *Pleuromya* " *tellina* ", *Pl. alduini* (Brong.) (= " *recurva* "), *Ostrea quadrangularis* Ark. (this may be the " *Gryphaea dilatata* " of Mr. Mathew's record ?), *Exogyra nana*, *Isognomon subplana* (Étall.), *Perisphinctes* sp. cf. *cloroolithicus*, with hollow gas chambers: many rolled and bored pebbles of claystone as in the Pebble Bed of N. Wilts, Berks, and Oxon . . .	1	0

Lower Calcareous Grit.	Ft.	in.
6. Clay and sand mixed, becoming more sandy and harder downwards, until it passes imperceptibly into the hard stone below. *E. nana*	1	8
5. Very hard block of blue-hearted yellow "grit-stone" covered with fucoidal markings. Part of a large *Perisphinctes* 11 inches in diameter, *Chlamys fibrosa*, *Exogyra nana*, *Lima rigida* (Sow.) *Camptonectes lens* (Sow.), *Modiola bipartita* Sow., *Modiola pulchra* Phil., *Ostrea gregarea* Sow., *Pleuromya* "*tellina*", *Trigonia* (fragments), *Isognomon* (fragments), *Nucleolites scutatus* Lamk., *Serpulae*	2½–3	0
4. Sandy clay and sand, brown and yellow, shaly	9	0
3. Ditto, very shaly, iron-grey, with large doggers	4	0
2. Impersistent band of hard blue gritstone	1	6
1. Iron-grey sandy shales, as above; seen to	2	0

Strata below Bed 1 were obscure, owing to the cutting having been sloped. Similar beds, perhaps lower than 1 in the sequence, could be made out on the east side of the short embankment carrying the road up to the bridge. West of the bridge no attempt was made to obtain measurements, owing to sloping of the cutting sides, but the Lower Calcareous Grit obviously had a considerable thickness —perhaps more than double the 21 feet actually measured east of the bridge.

The focus of interest in the section is the unmistakable representative of the Pebble Bed (Bed 7), with its profusion of Berkshire Oolite shells (especially the *Gervillia* and *Trigonia*). This is the most southerly point at which the bed has been detected (previously it was not definitely known south of Spirt Hill near Bremhill, north of Calne). The Pebble Bed has been taken throughout the Berkshire, Oxfordshire, and North Wiltshire outcrop to indicate the base of the Berkshire Oolite Series.[1] On the assumption that it still marks the same horizon at Westbury, all below it falls into the Lower Calcareous Grit. Bed 5 yields a richer fauna than is usual for the Lower Calcareous Grit farther north in the Faringdon ridge; but a still richer fauna occurs in grit-stones that seem to be below the Pebble Bed at Seend.[2] There is no reason for not accepting such a widespread Pebble Bed, invariably followed by a characteristic invertebrate assemblage, as one of the best time-planes available.

Beds 8 to 12 inclusive (12 feet) consisting, except for Bed 9, entirely of clays and marls, fall into line with the Highworth Clay and Highworth Grit (correlated with the Nothe Clay and Bencliff Grit of Dorset).[3] Both the grit and the clay are well developed above the Pebble Bed at Spirt Hill, near Bremhill, where 6 in. mapping carried out by the writer during 1931 and 1932, and information obtained from two sections, has proved a succession essentially comparable with that revealed by the Westbury cutting.[1] The Highworth Grit and Clay pass into one another and are interchangeable. At Westbury, as at Calne, no pure grit seems to have been deposited, though Bed 8 is distinctly sandy.

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[1] W. J. Arkell, 1927, "The Corallian Rocks of Oxford, Berks, and North Wilts": *Phil. Trans. Royal Soc.*, ccxvi B, 82–4.

[2] W. J. Arkell, 1933, *The Jurassic System in Great Britain*, 393.

[3] 1927, loc. cit., 91 et seq., and 158–9.

Bed 9 seems to indicate a temporary incursion of the Urchin Marls type of deposition, which prevailed along the Faringdon Ridge, for about 20 miles from Highworth to Marcham, immediately before the formation of the Highworth Clay.

I would like to conclude with a plea for the retention, in descriptions of English exposures such as this, of our familiar indigenous stratigraphical nomenclature. Mr. Mathew classifies the beds just enumerated into Kimmeridgian, Corallian, and Oxfordian. The terminations *-ian* indicate that he uses the names as *stages*, after the manner of d'Orbigny. But, if so, the term Corallian is incorrectly used. The strata so classed at Westbury are not the Corallian Stage of Thurmann and d'Orbigny, which falls within what is here called Kimmeridgian. They are the *Corallian Beds, sensu anglico*, which are a local subdivision of the Oxfordian Stage of Brongniart, Marcou, and d'Orbigny. Consequently, to use the term Oxfordian only for strata below the Corallian Beds is inaccurate. When it is used, as in the paper under consideration, for the lower half of the Corallian Beds, without any reference to the English stratal terms such as Lower Calcareous Grit, it is not only inaccurate but misleading.

The Relative Seismicity of Different Regions of the World.

By Charles Davison, Sc.D., F.G.S.

The seismicity of any region depends partly on the frequency, and partly on the intensity, of the earthquakes that occur within it. If earthquakes of all intensities are included in making such estimates, the weight to be given to the intensity must at present be to a great extent arbitrary. If, however, the determination is confined to earthquakes of the highest degrees of intensity, the results, though incomplete as representatives of the actual seismicities of the various regions considered, may yet give with some approach to accuracy their relative order of magnitude. The object of this brief paper is to provide such estimates for the various regions of the world and for the provinces of Italy that are shaken by destructive earthquakes.

The catalogues used for this purpose are: (1) Professor Milne's valuable list of destructive earthquakes from the year A.D. 9 to 1899, and (2) Professor Cavasino's important table of the numbers of earthquakes of different intensities according to the Mercalli scale in the various provinces of Italy.[1]

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[1] Arkell, 1933, loc. cit., 391–2. A reference to the discovery of the Pebble Bed in the Westbury cutting could only be included as a footnote before going to Press.

Professor Milne assigned to each earthquake its intensity according to a simple scale of three degrees, namely :—

1. Walls cracked, chimneys broken, or old buildings shattered.
2. Buildings unroofed or shattered and some thrown down.
3. Towns destroyed and districts desolated.

In Table 1 the value of the seismicity is obtained from earthquakes of greatest destructive power (intensities 3 and 2) during the century 1800–1899, the list for this interval and for shocks of such strength being in all probability nearly complete. The estimates of the areas of the regions differ rather widely. The values adopted in Tables 1 to 3 are those given about the close of the nineteenth century. In each region the number of earthquakes is multiplied by one million and the product is divided by the number of square miles in the area of the region, so that the figures given represent the average number of earthquakes per million square miles during the nineteenth century. The record for New Zealand, it should be mentioned, begins with the year 1848, and the figure obtained has therefore been increased in the ratio 100 : 52.

TABLE 1.

Region.	*Number of earthquakes.*	*Area in sq. miles.*	*Relative seismicity.*
Salvador	15	7,225	2076
Greece	37	25,040	1478
Italy	62	101,361	612
Philippines	71	116,000	612
Moluccas	6	10,000	600
West Indies	29	96,551	304
Japan	42	155,000	271
Turkey	16	65,909	243
Asia Minor	48	220,000	218
Guatemala	10	46,600	215
Iceland	6	40,300	149
Java	6	49,000	122
New Zealand	6	106,240	109
Costa Rica	2	21,495	93
Nicaragua	4	51,650	77
Spain and Portugal	17	226,908	75
Formosa	11	14,978	73
Ecuador	7	100,000	70
Honduras	3	46,500	65
California	10	155,980	64
Chile	19	307,774	62
Mexico	42	751,000	56
Sumatra	7	165,600	42
Algeria	9	255,000	35
France	7	206,381	34
China	59	2,000,000	30
Persia	18	638,000	28

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[1] J. Milne, *Brit. Ass. Rep.*, 1911, 649–740; A. Cavasino, *Ital. Soc. Sism. Boll.*, xxx, 1931–2, 215–16.

Region.	*Number of earthquakes.*	*Area in sq. miles.*	*Relative seismicity.*
Austria-Hungary	6	240,456	25
Peru	14	676,638	21
India	27	1,350,000	20
Russian Turkestan	8	410,000	20
Alaska	10	531,400	19
Venezuela	6	417,000	14
Colombia	7	513,938	14
United States	22	3,025,000	7
Bolivia	4	536,000	7
Russia	8	2,095,000	4
Argentina	3	1,125,080	3
Siberia	7	4,833,500	1

It will be noticed that the first place is occupied by the smallest region. If Salvador and the adjoining coast state of Guatemala are taken together, their total area is 53,825 square miles and the resulting seismicity is 465. For the same reason, it is possible that the value for the Moluccas is too high. Thus, the order, as regards seismicity, should perhaps be: Greece 1,478, Italy 612, Philippines 612, Salvador and Guatemala 465, West Indies 304, Japan 271, and so on.

Again, for the last fourteen regions in this Table, six contain more than one million square miles and only one less than 400,000 square miles. Countries of such vast size probably include large aseismic tracts as well as smaller regions in which destructive earthquakes are of common occurrence. For instance, in the United States, only six states have been disturbed by destructive earthquakes of intensities 3 or 2, and only two by more than one. The relative seismicities for the whole country, California, and Alaska are 7, 64, and 19. Again, for the whole of China, the corresponding figure is 30, but higher figures are reached in the five provinces in Table 2.

Table 2.

Province.	*Number of earthquakes.*	*Area in sq. miles.*	*Relative seismicity.*
Kiangsu	10	45,000	222
Shantung	8	56,000	143
Chihli	4	58,950	68
Yunnan	9	134,000	67
Shensi	3	75,000	40

For the whole Christian era, the figures (reckoned per century) for the provinces most frequently shaken are: Chihli 36, Kiangsu 32, Shansi 19, Shantung 18, Shensi, 15, Fukien 14, Yunnan 14, Honan 9, Chehkiang 7, Anhiu 7, Kansu 7, Hupeh 3, and Szechuan 3, and for the whole of China 7.

Eight European countries, including Iceland, are considered in Table 1. The results given in Table 3 for five others depend on earthquakes that, with few exceptions, were of intensity 1 or were of semi-destructive strength.

TABLE 3.

Region.	*Number of earthquakes.*	*Area in sq. miles.*	*Relative seismicity.*
Switzerland	32	15,981	2002
Scotland	5	29,820	168
England	7	50,823	138
Germany	22	211,168	104
Norway and Sweden	10	295,139	34

For destructive earthquakes of all intensities, the corresponding figures for the other countries would be: Italy 4,380, Greece 2,756, Turkey 394, Iceland 372, Austria-Hungary 333, Spain and Portugal 251, France 179 and Russia 11.

Professor Cavasino's list, though it covers an interval of forty years, is of too short duration to give a fair representation of the relative seismicities of the different Italian provinces. For the interval considered, however, the results given in Table 4 are of some interest. They are for destructive earthquakes only (intensities 8–10, Mercalli), and the figures in the last column represent, as before, the number of earthquakes per century within an area of one million square miles.

TABLE 4.

Province.	*Number of earthquakes.*	*Area in sq. miles.*	*Relative seismicity.*
Tuscany	11	9,304	2,956
Calabria	5	5,819	2,148
Umbria	3	3,748	2,001
Latium	3	4,663	1,608
Campania	4	6,289	1,590
Emilia	5	7,967	1,569
Sicily	6	9,936	1,510
Marches	2	3,763	1,329
Abruzzo and Molise	3	6,380	1,176
Venetia	3	9,476	791

The Sequence and Structure of the South-east Portion of the Leicestershire Coalfield.

By Professor W. S. BOULTON, D.Sc., A.R.C.S., M.Inst.M.E., F.G.S.

IN 1916 the Whitwick, South Leicestershire, and Ellistown Collieries put down a boring near Ellistown Colliery in Leicestershire to prove the measures below the Deep or Roaster Coal. Early in the following year Professor W. W. Watts and I examined in detail the cores of this boring, and collected samples of the rocks and fossils from them. The rock-descriptions in the journal of the boring-foreman were checked and in many cases altered and enlarged by Professor Watts and myself after examining specimens in the laboratory, some of them in thin slices under the microscope. Mr. R. Bullen Newton, of the Natural History Museum, was good enough to name some of the fossils.

As the information thus gained throws some new light upon the southerly extension of the Leicestershire Coalfield, and on the nature and thickness of the Lower Carboniferous rocks of the area, and since it is now possible by the kind permission of the proprietors of the above collieries to make public the results, a brief description of the cores and of the stratigraphical sequence and structure of this part of the Coalfield is here given.

The site of the boring is adjacent to Ellistown Colliery, three-quarters of a mile north of Bagworth Railway Station, and 560 feet above O.D. The measures proved at Ellistown Colliery down to a depth of 996 feet, a few feet below the Roaster Coal, are recorded in the Geological Survey Memoir (*The Geology of the Leicestershire and South Derbyshire Coalfield*, C. Fox-Strangways, pp. 299–302).

The following is the new boring record, starting at a depth of 997 feet, which is here 15 feet above the Roaster Coal.

	Depth.				*Thickness.*		*Description of Strata.*
	Ft.	in.	Ft.	in.	Ft.	in.	
	977	0–	978	0	1	0	Coal.
	978	0–	986	0	8	0	Fireclay.
	986	0–	992	0	6	0	Fireclay.
	992	0–	997	0	5	0	Old Goaf (Roaster seam).
	997	0–	1,002	0	5	0	Old Goaf (Roaster seam).
Lower Coal Measures.	1,002	0–	1,016	0	14	0	Fireclay.
	1,016	0–	1,017	0	1	0	Hard rock.
	1,017	0–	1,019	0	2	0	Fireclay.
	1,019	0–	1,025	0	6	0	Bind.
	1,025	0–	1,033	6	8	6	Sandstone rock.
	1,033	6–	1,040	0	6	6	Bind.
	1,040	0–	1,044	0	4	0	Bind with vertical breaks.
	1,044	0–	1,044	6		6	Compact limestone (no fossils).
	1,044	6–	1,048	0	3	6	Bind.
	1,048	0–	1,052	6	4	6	Black shale.
	1,052	6–	1,054	0	1	6	"Cannel coal."
	1,054	0–	1,055	6	1	6	Hard black rock.
	1,055	6–	1,092	0	36	6	Bind (1,063–1,084 fine grey mudstone barren of fossils).
	1,092	0–	1,100	6	8	6	Very black shale.
	1,100	6–	1,106	0	5	6	Soft bind.
	1,106	0–	1,111	0	5	0	Fireclay.
	1,111	0–	1,114	0	3	0	Sandy bind.
	1,114	0–	1,135	0	21	0	Sandstone.
	1,135	0–	1,195	0	60	0	Pale grey micaceous sandstone.
	1,195	0–	1,231	0	36	0	Fine silty sandstone with layers of clay.
	1,231	0–	1,232	0	1	0	Firm fireclay.
	1,232	0–	1,240	0	8	0	Fireclay containing ironstone nodules.
	1,240	0–	1,245	0	5	0	Fireclay.
	1,245	0–	1,250	0	5	0	Soft black mudstone.
	1,250	0–	1,255	0	5	0	Fireclay.
	1,255	0–	1,259	0	4	0	Black bind containing hard bands of fireclay.
	1,259	0–	1,261	0	2	0	Red fireclay.
	1,261	0–	1,273	6	12	6	White Sandstone with some conglomerate.
	1,273	6–	1,274	0		6	Bind.

	Depth.				*Thickness.*		*Description of Strata.*
	Ft.	in.	Ft.	in.	Ft.	in.	
Lower Coal Measures.	1,274	0–	1,276	0	2	0	Sandy bind.
	1,276	0–	1,278	6	2	6	Black bind.
	1,278	6–	1,294	6	16	0	Fireclay.
	1,294	6–	1,294	9		3	Spore coal.
	1,284	9–	1,296	0	1	3	Seat stone (sandy bind with plants).
	1,296	0–	1,301	0	5	0	Highly slickensided clay passing into clay ironstone.
	1,301	0–	1,302	0	1	0	Alternations of white sandstone with black bind.
	1,302	0–	1,309	0	7	0	White sandstone, fine grained.
	1,309	0–	1,313	0	4	0	Black bind, very smooth.
	1,313	0–	1,318	0	5	0	Sugary white sandstone passing into sandy shale.
	1,318	0–	1,327	0	9	0	Black bind.
	1,327	0–	1,330	0	3	0	" Fireclay."
	1,330	0–	1,342	0	12	0	Hard sandstone.
	1,342	0–	1,345	0	3	0	Soft sandstone, with some argillaceous partings in upper part.
	1,345	0–	1,348	6	3	6	Typical Coal-measure sandstone, with streaks of coal.
	1,348	6–	1,386	0	37	6	Sandy bind, rather more sandy than at 1,400. Grey, with white mica, and plant remains.
	1,386	0–	1,417	0	31	0	Smooth bind, with few slickensides, fracture nodular at 1,400. *Gastrioceras listeri*, *Pterinopecten papyraceus*, and *Lingula*.
	1,417	0–	1,420	0	3	0	Brown bind.
	1,420	0–	1,426	0	6	0	Grey bind.
	1,426	0–	1,427	0	1	0	Firm " fireclay ".
	1,427	0–	1,431	0	4	0	Very fine grey silty sandstone, coarser above. Plants 1,430–1.
	1,431	0–	1,435	0	4	0	" Fireclay."
	1,435	0–	1,450	0	15	0	Grey bind with ? *Naiadites* and *Discina*.
	1,450	0–	1,451	0	1	0	Grey bind with ? *Naiadites* and *Discina*.
? Millstone Grit.	1,451	0–	1,454	0	3	0	Fine grey sandstone.
	1,454	0–	1,459	0	5	0	White kaolinized sandstone sometimes false bedded ; dark micaceous streaks.
	1,459	0–	1,461	0	2	0	Bind with small *Lingula*.
	1,461	0–	1,474	0	13	0	Fine sandstone, white and sugary.
	1,474	0–	1,477	0	3	0	" Fireclay."
	1,477	0–	1,483	0	6	0	Fine grey sandstone.
	1,483	0–	1,488	6	5	6	Bind, with false bedded grit with large angular grains and *Lingula mytiloides*.
	1,488	6–	1,489	0		6	" Fireclay."
	1,489	0–	1,494	0	5	0	Clay, with much pyrites and slickensides.
	1,494	0–	1,497	0	3	0	Bind, with *Lingula mytiloides* and slickensides.
	1,497	0–	1,508	0	11	0	Fine green grit.
	1,508	0–	1,509	0	1	0	Grit, with pink and green quartz fragments.
? Pendleside Beds.	1,509	0–	1,511	0	2	0	Fine-grained limestone.
	1,511	0–	1,523	9	12	9	Fine bind, pearly and brown in colour. *Orbiculoidea nitida*, scales of *Megalichthys* and *Lingula*.
	1,523	9–	1,525	9	2	0	Blue " fireclay " with plants. Gritty calcareous bed (sandstone with cement of some carbonate).
	1,525	9–	1,534	0	8	3	Bind, with *Lingula*.
	1,534	0–	1,535	0	1	0	Sandstone, with mica flakes.

	Depth.				*Thickness.*		*Description of Strata.*
	Ft.	in.	Ft.	in.	Ft.	in.	
Carboniferous Limestone.	1,535	0–	1,539	6	4	6	Dolomite, grey, sandy in texture, with cavities lined with dolomite crystals.
	1,539	6–	1,540	0		6	Sandy dolomite (foraminifera, shells, and crinoids in grit with carbonate cement.
	1,540	0–	1,542	6	2	6	Fine micaceous sandstone.
	1,542	6–	1,547	0	4	6	Dolomite, with rhombs in cavities. Abundant fine quartz dust.
	1,547	0–	1,550	0	3	0	Dolomite, with very fine quartz dust.
	1,550	0–	1,554	0	4	0	Dolomite or limestone with gritty texture.
	1,554	0–	1,555	6	1	6	Dolomite or limestone with gritty texture.
	1,555	6–	1,558	6	3	0	Granular dolomite containing fragments of black fossiliferous limestone.
	1,558	6–	1,563	0	4	6	Dolomite.
	1,563	0–	1,568	0	5	0	Gritty dolomite.
	1,568	0–	1,569	0	1	0	Dolomite.
	1,569	0–	1,569	6		6	"Grey rock."
	1,569	6–	1,573	6	4	0	Sandy bind.
	1,573	6–	1,579	0	5	6	Fine dark gritty shale, with shell casts, some of them preserved in calcite (a scabriculate *Productus*).
	1,579	0–	1,592	0	13	0	Dolomite vein in coarse dolomite rock. Yellow grey dolomite or limestone with thin chert at base.
	1,592	0–	1,600	0	8	0	Fine shale, sandy dolomite some black and bituminous, with iron pyrites and fossils.
	1,600	0–	1,604	6	4	6	Fine dark limestone.
	1,604	6–	1,609	6	5	0	Soft sandstone.
	1,609	6–	1,613	6	4	0	Coarse crinoidal limestone with shells below little black bind with spines.
	1,613	6–	1,621	0	7	6	Grey limestone with brachiopod and foraminiferal remains. *Endothyra bowmani*.

Close of boring.

The top of the *Carboniferous Limestone* is at a depth of 1,535 feet, and since the base was not reached at 1,621 feet, the thickness here must be upwards of 86 feet. In the limestone inliers on the north-east border of the Leicestershire Coalfield, Parsons has shown (L. M. Parsons, "The Carboniferous Limestone bordering the Leicestershire Coalfield," *Q.J.G.S.*, lxxiii, 2, 1917) that the thickness there is upwards of 900 feet. In the Desford Boring, 5½ miles south-east of Ellistown, the thickness is only 27 feet, with its base on Charnian rocks, so that the limestone is thinning rapidly in a southerly direction against the Pre-Cambrian floor. The general characters of the limestone in the Ellistown Boring tally with those described by Parsons in the outcrop areas to the north, the upper 55 feet being markedly dolomitic, while the lower 30 feet are more normal limestone. Many of the beds are very fossiliferous, with the fossils often in a fragmentary condition. They include crinoids, brachiopod spines, ostracods, and foraminifera, and among them a scabriculate *Productus* and *Endothyra bowmani* were identified.

Between the top of the Carboniferous Limestone and the Roaster

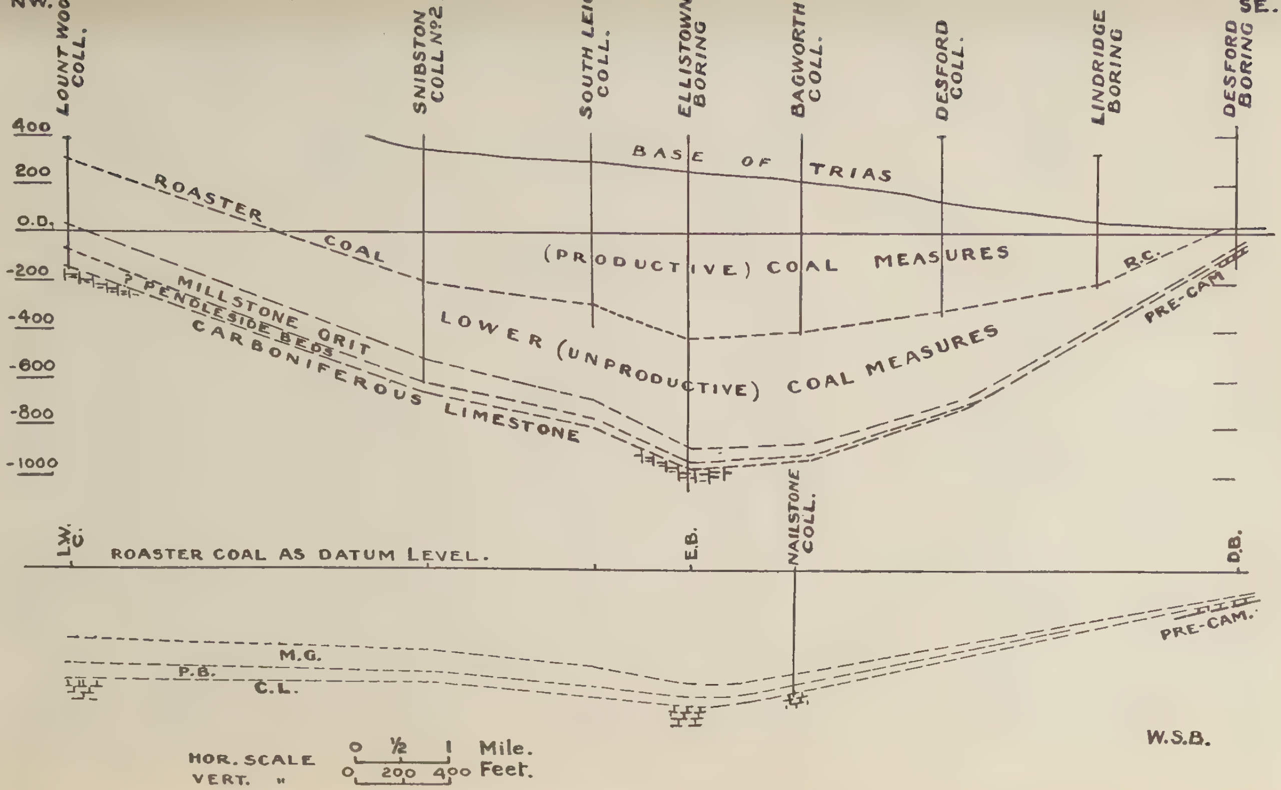

FIG. 1.—Longitudinal Section showing the relation of the rocks in the Ellistown Boring to those in Colliery Shafts and Borings in the South-Eastern part of the Leicestershire Coalfield.

Coal are about 533 feet of measures which call for some comment. Nowhere in the cores were there any signs of unconformity or faulting, nor did Parsons find any evidence of unconformity in the series from Coal Measures to Limestone in the outcrop areas to the north.

The question arises as to whether the Millstone Grit and the Pendleside Beds are represented in the 533 feet of measures above the limestone.

In the Leicestershire and South Derbyshire Coalfield the Roaster Coal has been generally taken as the lowest workable seam in the eastern part of the Coalfield, and the Coal Measures below it have been classed as Lower or Unproductive Measures.

The paucity of zone fossils found in the cores of the Ellistown Boring makes it difficult to assign with any confidence the limits of the Millstone Grit and Pendleside Beds between the Coal Measures and the Limestone. At a depth of 1,410 feet, *Gastrioceras listeri* occurs, associated with *Pterinopecten papyraceus*, and this cephalopod is now regarded as of Lower Coal Measure age in the north of England. Between a depth of 1,451 and 1,509 feet, the succession is mainly fine grey sandstones and green grits, and this assemblage, 58 feet thick, probably represents the *Millstone Grit*. On the north-east border of the Coalfield the Millstone Grit varies from 200 to 300 feet in thickness, and consists of yellowish-white grit, conglomeratic at the base. At Lount Wood Colliery, 6½ miles north-west of the Ellistown Boring, a Millstone Grit facies begins at 262 feet below the Roaster Coal, and continues for 111 feet; while a hitherto unpublished record of a boring below the Main Seam at Snibston No. 2 Shaft, 2¾ miles north-west of Ellistown, shows 84 feet of white sandstone, which probably represents the Millstone Grit. At the Desford Boring to the south 12 feet of sandstone and shale above the Carboniferous Limestone has been assigned to the Millstone Grit, and it probably thins out and disappears altogether a short distance farther to the south.

Between the top of the Limestone and the presumed Millstone Grit in the Ellistown Boring come 26 feet of shale for the most part (1,509–1,535 feet), with *Lingula*, *Orbiculoidea nitida*, and scales of *Megalichthys*, which may represent the "Pendleside" shales exposed in the Ticknall inlier to the north of the Coalfield, where they are about 35 feet thick.

The longitudinal section through the south-east part of the Leicestershire Coalfield (Fig. 1) shows the relation of the rocks met with in the Ellistown Boring to those in neighbouring colliery shafts and borings. The structure is a shallow and narrow basin, the long axis of which runs due north from Ellistown through Whitwick Colliery. Less than a mile east of this axis the Coal Measures rise steeply against the western boundary fault of Bardon Hill, while a mile to the west of the axis at Nailstone Colliery the Coal Measures are rising in the opposite direction, and outcropping against the base of the Trias. A little farther west in the longitude of

Market Bosworth they are absent, for at the latter place borings have proved that Permian Breccia is lying upon Stockingford Shales.

The extent of the pre-Triassic subsidence and folding is indicated in the upper section by the Roaster Coal, and the post-Triassic movement by the southerly tilt of the base of the Trias. In the lower section, whose direction is slightly varied so as to take in the Nailstone Boring, where the Roaster Coal is taken as a datum level, the Lower Coal Measures are seen to thicken at Ellistown, which suggests that subsidence was taking place along the axis of the basin during that time, and as a consequence of downward movement on the western side of the Bardon Fault.

REVIEWS.

THE DEFORMATION OF THE EARTH'S CRUST: By WALTER H. BUCHER. pp. 518, with 100 figures. Princeton University Press, 1933.

IN this book Bucher attempts to derive from geological facts of a general nature a picture of the mechanics of diastrophism. It is a large undertaking, and that many will disagree with some of his conclusions is only to be expected. The work is attractively written and will undoubtedly stimulate critical thinking.

The author gives his geological facts in the form of " Laws ", and these are usefully listed at the end of the book in an appendix. Law 3, for example, says that, " In ground plan, the forms of crustal elevations and depressions represent two types. First, elevations and depressions which are essentially equidimensional (swells and basins), and second, others that show a distinct linear development with one horizontal dimension decidedly greater than the other (welts and furrows)." For each law examples are discussed. These are taken mostly from America and the Alps, and the descriptions are often in such detail that they are intended to be used with additional maps.

In addition to the laws there is a series of personal interpretative conclusions which are described and numbered consecutively as " Opinions ". A tabulated list of the opinions would have been an advantage to the reader, for though they are printed in italics they are not nearly so easy to find as the laws, which are in heavy type.

It is not possible here to do more than hint at the importance of Bucher's reasonings. Twelve chapters are devoted to the structure and relationship of the orogenic belts of the earth. The subjects dealt with include the Pattern, the Deformation, and the Space and Time Relations of the Mobile Belts, Heterogeneous and Homogeneous Mobile Belts, Fracture Belts of Low Mobility, Isostasy, and Intrusives. Under these subjects such topics as Continental Drift, Rift Valleys, and Zonal Migration of Geosynclines are dealt with. The thirteenth chapter deals with Epeirogenesis and treats of eustatic movements of the crust, similarities and parallelisms in opposite shore lines, and the general shape and grouping of the continents.

Emphasis is given throughout the book to the concept of crustal deformation due to both tension and compression. The discussion of the effects of tension are particularly interesting. Opinion 14*a* states that, " The pattern of the fractures produced in a thin, spherical shell by tensional stresses due to the expansion of the subcrustal interior resembles, in general as well as in its details (deflections, virgations and syntaxis, linkage), that of the Mesozoic-Cenozoic geosynclines and the ensemble of modern welts (newly folded as well as rejuvenated welts), the Hindukush-Pamir region representing the " focal bar " and the Pacific Ocean the " segment." Geosynclinal furrows are therefore looked upon as due to tensional stresses, and instead of the rising welts producing the furrows, Bucher believes that the furrows cause the rising of the welts. The following quotation gives a good idea of his views.

" We assume by way of hypothesis that when a portion of the crust suffers tension, it responds in such a way that the surface of a relatively narrow belt becomes lowered with reference to the surrounding surface, forming a furrow which may be hundreds of miles wide. If it drops low enough, this will develop into a seaway. While tension lasts, the adjoining land is thought to remain passive.

" The tensional stress is assumed to decrease eventually to zero. But the same process which brought it to an end is assumed to continue, producing compression in this part of the crust. Under compression, the furrow on the surface acts as a notch does in a beam. It creates a line of weakness. If the depression is asymmetrical in cross-section, the side with the sharper flexure is the line where the stresses are localized. Here the higher side tends to be bulged up in the form of a welt, during epochs of compression. While compression lasts, the adjoining furrow lies essentially passive.

" After a lapse of time, the stresses are reversed and sinking is resumed under renewed tension, only to be followed again by compression and so on in ceaseless rhythm."

On this view, therefore, the formation of welts, under compression, is not due to differences in the strength of the crustal materials, but to the localization of the stresses in and along the furrows or geosynclines. What ultimately appears as the foreland escaped deformation because in it the crystalline basement stood higher. We understand also from this reasoning why, when a new mobile belt comes into existence after an older one has ceased to function, the newer may intersect the older at any angle (Law 37).

Bucher discusses the theory of continental drift in several connections and always rejects it. He thinks that the theory of drift is not necessary to explain the similarities in the pattern of opposed shore lines in continents and islands. Nor does he believe it necessary to understand the distribution of the Palaeozoic glaciation of the Southern Hemisphere. The general shape and grouping of the land masses is due in Bucher's opinion to the interplay of three factors, (a) the physical nature of the crust, (b) the presence of the mobile zones, and (c) the tendency of the relatively strong inert crust to assume a tetrahedroid shape when the subcrustal volume diminishes.

In connection with the resemblances between South African and South American geology, he says that we are deceiving ourselves if we mistake the similarities of their Lower Devonian faunas for something unique. He gives an instructive comparison between the Eastern Alps and the Himalayas, roughly 4,000 miles apart, in which he shows that actual contact is unnecessary to explain any or all of the resemblances between the two sides of the southern Atlantic. He thinks that it is at best doubtful whether the assumption of a former contact of South America and South Africa would prove sufficient to account for the ensemble of geological and palaeontological realities in the two continents. Bucher also rejects Wegener's hypothesis on the evidence of the time relations of the epochs of mountain folding. And, believing as he does that there is no great difference in the strength between the crust in oceanic areas and on the continents, his opinion is contrary to the belief in continental drift.

From these indications of the contents of this book it is obvious that it is a work which must be studied carefully by everyone interested in the earth's history. It is not intended as a textbook, but it will undoubtedly be useful to teachers and advanced students of geology. The specialist is expected to put the opinions to the test, and checking them by his own experience in the field, either recognize or reject them for himself. "In such a way alone can a body of recognized facts be created, without which there can be no real insight into the nature of diastrophism."

Abundant references, mostly to American and Continental works, are given as footnotes. British readers will notice the conspicuous absence of references to such subjects as the North-West Highlands of Scotland.

Of the hundred figures the majority are well reproduced, but the reviewer cannot help thinking that more care might have been taken with some which are so much reduced that it is only with a lens that names and contours can be made out. If, as is possible, the names do not have the importance in the book which they have in the original work from which the diagram is taken, it would have been better to have redrawn the figure in a form suitable for reduction. In other cases figures should be redrawn when the originals are defective, rather than have the defects reproduced in the book. The map and section in Figs. 78 and 79, for example, disagree in their ornaments and other respects.

Typographical errors are few.

W. J. McC.

THE DINOSAURS: A Short History of a Great Group of Extinct Reptiles. By Dr. W. E. SWINTON. pp. xii + 233. With 25 plates and 20 text-figures. London: Thomas Murby and Co., 1934. Price 15*s*. net.

THIS book, written by an acknowledged authority on the group of which it treats, is popular in style without sacrificing scientific accuracy. To the student of palaeontology who desires a concise summary of what is known concerning the Dinosauria it will be most serviceable, and the bibliographies of the more important literature of the main orders or sub-orders at the ends of the chapters will be a useful guide to more extended study. At the same time the work should appeal no less to the general reader, with little or no knowledge of science, for whose convenience a glossary of technical terms is provided. Moreover, the book is embellished by eighteen plates of restoration models and drawings made by Mr. Vernon Edwards, as well as by photographs of museum specimens, maps showing the probable distribution of land and sea during the three main divisions of the Mesozoic epoch, and text-figures by the author illustrating dinosaur anatomy.

After introductory chapters dealing with definitions and diagnoses of dinosaurs and descriptions of the face of the earth as it probably appeared when the dinosaurs flourished, the author proceeds to consider origins. Like most authorities at the present time, he adopts the theory originally put foward by Seeley that the Dinosauria are diphyletic, the two main orders of Saurischia and Ornithischia having sprung independently from the ancestral Pseudosuchia of the Triassic from which at different times the crocodiles and birds have also separately evolved. The next chapter on the anatomy and classification of dinosaurs is as elementary as the subject permits. This is followed by four chapters giving admirable accounts of the successive orders and sub-orders, beginning with the carnivorous dinosaurs and passing on to the giant amphibious sauropods, the bird-footed or beaked dinosaurs, and lastly the armour-plated forms with *Protoceratops* and its clutch of eggs.

The next chapter is upon the evidences of disease among the dinosaurs and various pathological conditions in the bones and joints are described, but so far palaeopathology has afforded no indications of widespread infections such as might have led to extinction. The problem of the sudden disappearance of the group is then dealt with and the author concludes that there was no particular cause of extinction, but rather a complex series of circumstances based on a fundamental geological change, complicated by other factors such as racial senescence and want of plasticity in the animals themselves, so that they could not adapt themselves to a new environment. The final chapters are upon methods of collecting and preserving dinosaur remains, and upon the value and importance of the study of this great group of reptiles.

The author is to be congratulated on having produced the first comprehensive book on the dinosaurs, and one which has the merit of considerable originality.

F. H. A. M.

REPORTS AND PROCEEDINGS.

MINERALOGICAL SOCIETY.

7th June, 1934.

Professor C. Palache : The form-relations of the lead oxychlorides, laurionite, paralaurionite, and fiedlerite. The separate identity of each of the first two minerals is confirmed and their homoeomorphism is exhibited by a reorientation of laurionite. The form series of fiedlerite has been simplified by the choice of a new unit form. New forms are described on paralaurionite and fiedlerite. The crystallography of all three species is summarized in new angle tables, and their habits are illustrated by a series of drawings.

Mr. F. A. Bannister : The crystal-structure and optical properties of matlockite (PbFCl). W. Nieuwenkamp's recent work proving the identity of matlockite with artificial lead fluochloride (PbFCl) has been confirmed. New chemical analyses, X-ray work, and optical measurements have been made on single crystals of matlockite from Cromford, Derbyshire. Single-crystal photographs of the mineral have also confirmed the crystal-structure proposed for artificial PbFCl. Artificial BiOCl, BiOBr, and BiOI have crystal-structures of the same type and the relationship between matlockite and these and other compounds is discussed. Artificial Pb_2OCl_2 has a crystal-structure quite different from that of matlockite. Mendipite, $Pb_3O_2Cl_2$ contains no fluorine and it is improbable that fluorine has been overlooked in the oxychloride minerals from Laurium, Greece.

Dr. V. Zsivny and Dr. L. Zombory : Berthierite from Kisbánya, Carpathians. This rare mineral, previously known from two localities in old Hungary, is now described from a third, namely Kisbánya in comitat Szatmár (now Chiumbaia in Satu Mare, Romania) where it occurs as bundles of needles with stibnite and rhombohedral carbonates. Analysis agrees closely with the formula $FeS.Sb_2S_3$, but the specific gravity—4·65—is much higher than values previously recorded.

Dr. L. J. Spencer: Beryllium minerals (euclase and phenakite) from Africa. Apart from beryl, there are very few recorded occurrences of beryllium minerals in the whole of Africa. Euclase is described from pegmatite on the Lukangasi mica claim, Morogoro district, Tanganyika Territory. The main crystal on the single specimen collected measures 7·2 by 3·5 cm., being much larger than any euclase crystal hitherto known. Seventeen crystal-forms were determined. Small crystals of phenakite from pegmatite at the Klein Spitzkopje, South-West Africa, are of two distinct habits, prismatic and lenticular.

Mr. A. C. Skerl and Mr. F. A. Bannister: Lusakite, a cobalt-bearing silicate from Northern Rhodesia. The mineral occurs embedded in quartz-magnetite-kyanite-rock of gneissoid appearance from 80 miles east of Lusaka, Northern Rhodesia. Crystals, generally tabular to (010) varying up to 5 mm. in length, are black in hand-specimens, but show a deep cobalt-blue colour and strong pleochroism in thin section. The mean refractive index is approximately 1·74 and 2V is near 90°. Oscillation, Laue, and rotation photographs show that lusakite has an orthorhombic unit cell with edges *a* 7·86, *b* 16·62, *c* 5·63 Å., and space group V^1h^7. The unit cell contains $8[RO.Al_2SiO_5]$ where R represents Fe, Co, Ni, Mg, Al, and H. The cobalt content is unique for a silicate and reaches $8\frac{1}{2}$ per cent CoO or nearly two atoms of cobalt per unit cell. It is almost identical in physical properties with staurolite and X-ray photographs show that it possesses the same type of crystal structure.

Dr. A. W. Groves: The determination of small amounts of copper in rocks. The paper describes the application to silicate analysis of the sodium diethyl-dithio-carbamate colorimetric method for copper. Data on the retention of copper by the ammonia precipitate are given. The method has a range of about 0·001 to 0·25 per cent CuO when a sample of 2 grams is used.

Dr. L. J. Spencer: Thirteenth list of new mineral names. A dictionary list of 112 names collected from the literature of the past three years. Since the first list in 1897 a total of 1918 names has been collected.

Dr. L. J. Spencer: A new meteoric stone from Silverton, New South Wales. A beautifully-oriented stone weighing 351 grams was found by Mr. R. Bedford amongst debris in the old museum at Port Adelaide, which has recently been reorganized as a Nautical Museum. It probably dates from the time (1883) of the discovery of the rich mineral deposits at Broken Hill in the Silverton district. The stone is a white hypersthene-olivine-chondrite of the Baroti type with only little nickel-iron.

Mr. M. H. Hey: Studies on the zeolites. Part VIII. A theory of the vapour-pressure of zeolites. An equation for the water-vapour pressure of a zeolite (or other compound showing similar dissociation phenomena) is derived on simple kinetic grounds, and is shown to agree reasonably well with the available experimental data. The equation, which can only be a first approximation to the truth, is compared with other equations previously proposed. Kinetic treatment also leads to a reasonable equation for the rate of diffusion of water within a zeolite crystal. The condition of the water in the zeolites is discussed.

CORRESPONDENCE.

ATLANTIC SUBSIDENCE.

SIR,—In the GEOLOGICAL MAGAZINE for February and April Cosmo Johns suggests a temporary lowering of the oceans in Quaternary time of the magnitude of about 3,000 feet.

As only a fraction of this could be used in the formation of Continental ice-sheets, the major action must have been the deepening of the oceanic basins. As the floors can only sink when space becomes available for them, there must have been lateral movement wedging out and elevating the Continental segments. If the suggested re-elevation had taken place in the ocean floors, where there is neither accumulation nor denudation, the submarine contours should show it.

In 1930, by using all the deep soundings in the possession of the Admiralty, I was able to contour the bottom of the Atlantic. This detailed work, while confirming the general outline of the published bathygraphical maps, revealed a number of troughs radiating outwards from the extensive flat oceanic plains into both the mid-Atlantic Rise and the Continental margins. These troughs fork until they die out as single faults. They are recognized on the coasts as bays, estuaries, and fjords.

Except possibly in their upper courses, " drowned " rivers are structural and not erosion features ; the stream having taken the easiest path, which is frequently a line of dislocation. As these troughs go right down to the deepest oceanic levels, frequently over 15,000 feet below the surface, they cannot be caused by erosion as there would have been no place available for the sea itself.

This structure of a basin with troughs radiating into the margin is typical of a depressed area. The last movement in the Atlantic basin is shown to be depression and there is no indication of any extensive elevation ever having taken place. This is more evidence in favour of the old theory of permanence of ocean basins.

Major faults that have been active since Carboniferous time illustrate the rule that when a fault develops in a structure the drop continued to be repeated in the same direction until the strain is taken up by a major movement elsewhere.

There are planets with more than one satellite and the Earth after developing one moon would retain the tendency to produce more. It is not unreasonable to consider the continents as aborted moons. There is no insulation against gravity and sub-crustal rock tides are ready to act when conditions are favourable for the migration of sub-crustal material. The general movement would be to wedge out the continental segments and transfer material laterally into them from the uppermost layers of the plastic zone of the sial of the oceanic floors. The result is a continued deepening of the oceanic basins, a thinning of the sub-oceanic sial, and an increase in the thickness of continental sial. Denudation has little effect as the products are deposited on the continent itself or on its flanks.

The Atlantic submarine contouring gives no support to the theory of continental drift but indicates a drift of sub-crustal oceanic sial into the continental areas.

LESLIE H. OWER.

THE RHODESIAN MUSEUM,
P.O. BOX 240,
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SOUTHERN RHODESIA.
8th May, 1934.